Engineering Materials and Design

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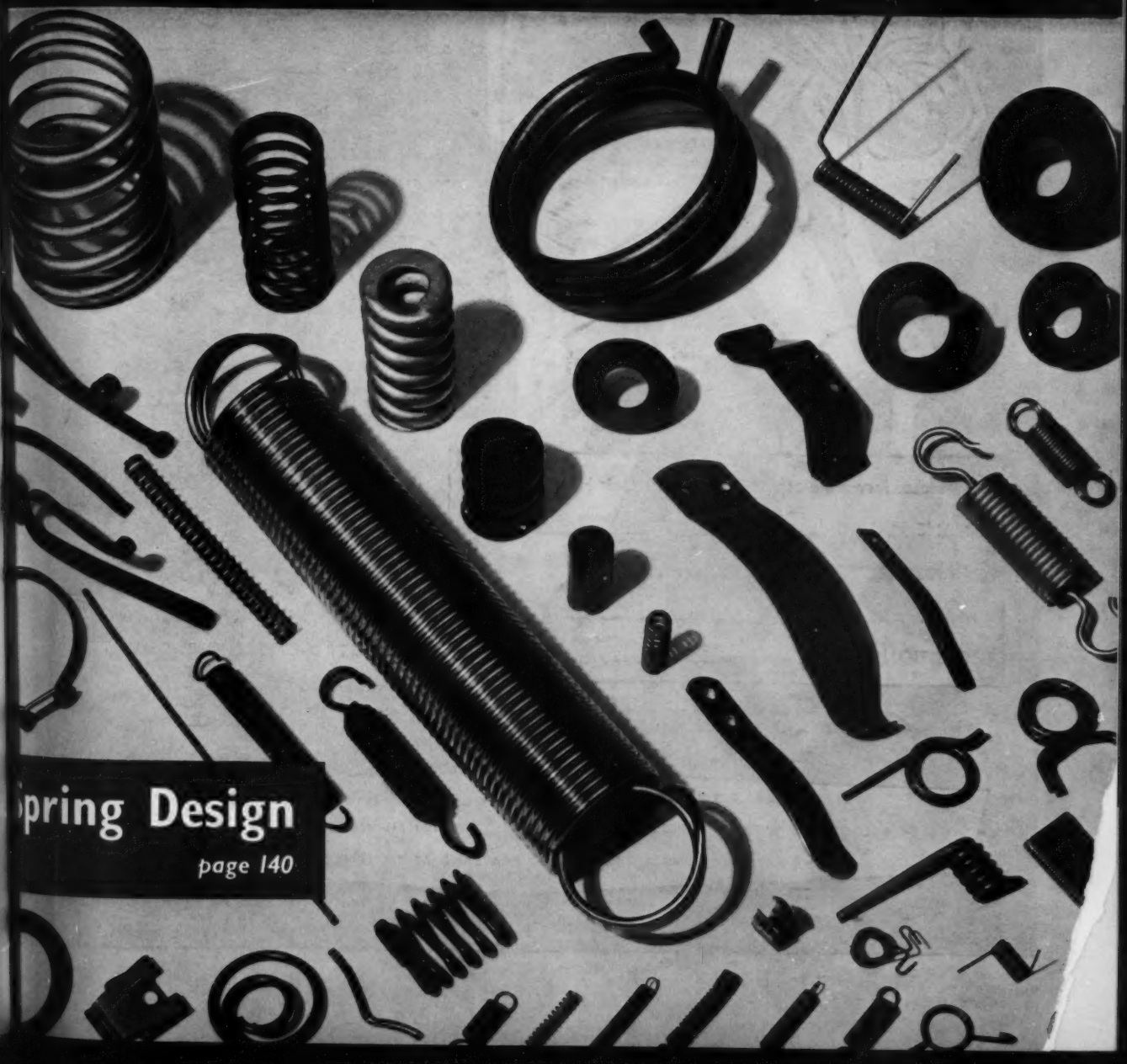

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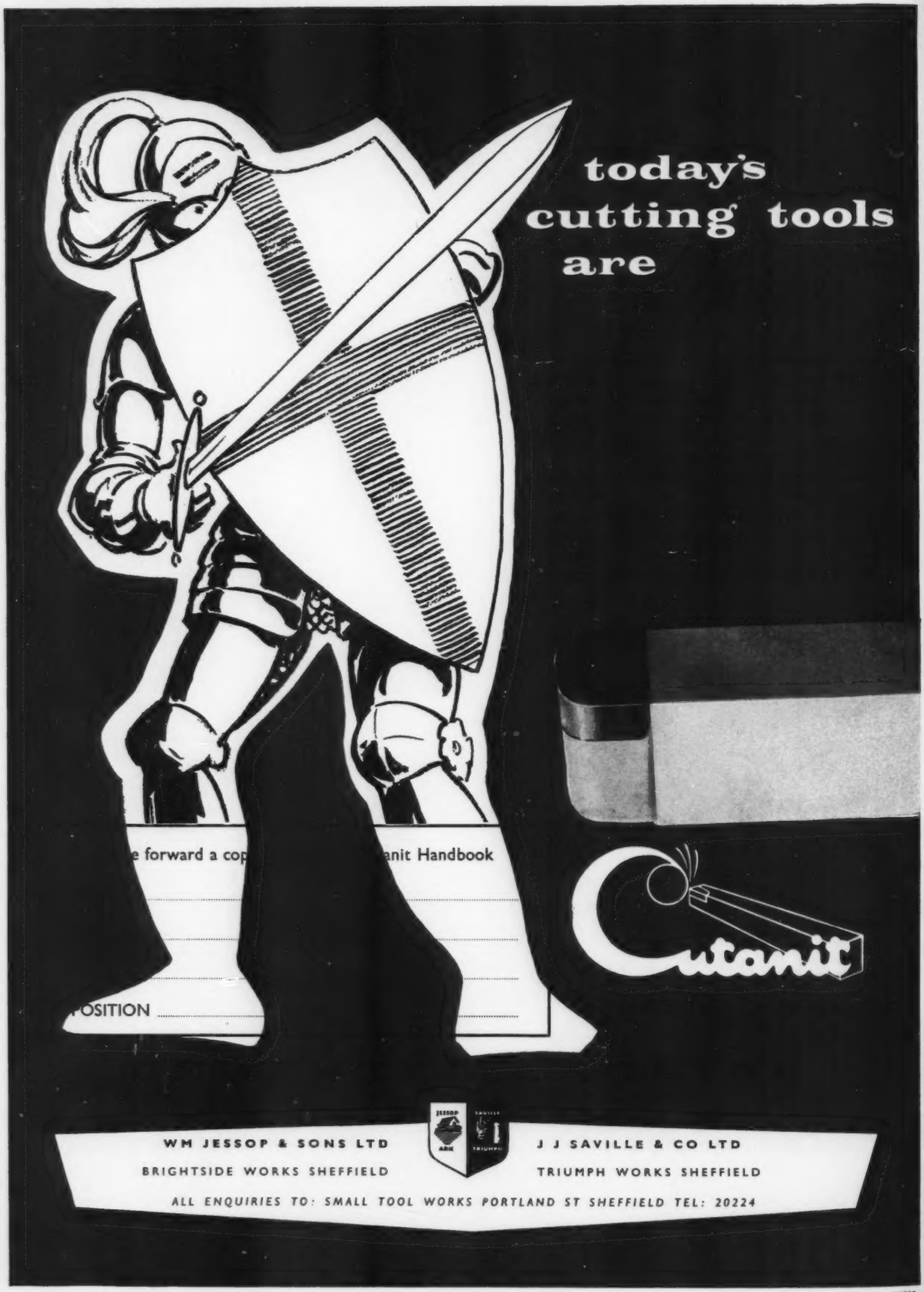
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Engineering Materials and Design

★ *The Magazine for Engineering Designers*

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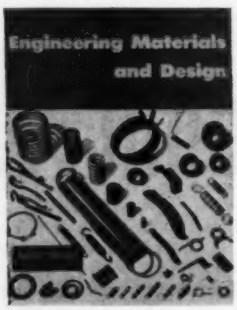

COVER—A selection of various types of compression and extension spring currently available to the designer. (By courtesy of Herbert Terry & Sons Ltd.)

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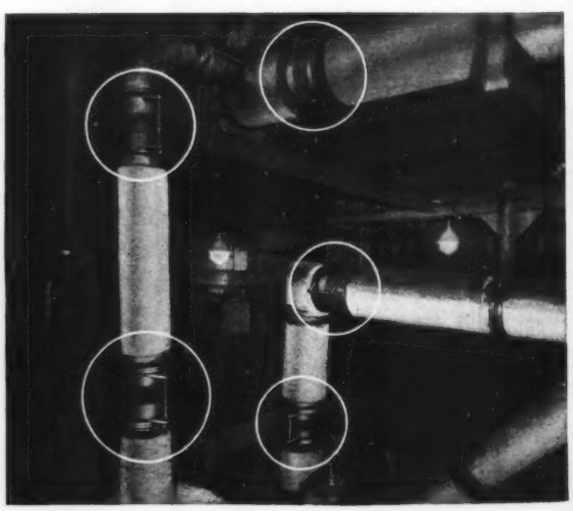


MATERIALS IN THE NEWS

Monthly Digest of Materials and Design News from Home and Abroad

S.W.G. to Stay

THE BRITISH STANDARDS INSTITUTION Committee MEE/-/7, which is studying the problem of multiplicity of basic sizes for sheet, strip and wire in current use, has just announced some of its conclusions reached so far.

One is that the S.W.G. is too well established to supplant in the U.K., and that there is no hope of this being established as an international series under I.S.O. auspices.

At the same time, the committee considers that it cannot contemplate the adoption in the U.K. of the range of thicknesses represented by the American preferred number series in inches, because it would lead to confusion. A proposal that the S.W.G. be modified to bring it into line with the American series is also rejected as impracticable. It is felt that there is no adequate reason at present to disturb the current use here of S.W.G. and B.G.

The committee recognises that if it cannot support the American proposal there is little hope of securing agreement among the inch-using countries on an inch series of thicknesses for the I.S.O. recommendation. For international purposes, the I.S.O. metric series already agreed on is regarded as sufficient and there would be no advantage in introducing a parallel inch series.

Finally, the committee suggests publication of a standard giving full information on the I.S.O. metric series as well as the series of gauges at present in general use in this country, and giving some clear guidance that may lead to a greater concentration of U.K. usage on the S.W.G. and B.G.

Largest Electric Clock

ONE OF THE MAIN FEATURES to be seen at this year's Electrical Engineers Exhibition, which opens at Earls Court on March 17, is what is thought to be the world's largest electric clock.

Made by the Synchronome Co. Ltd., it will be suspended from the roof of the Main Hall and will be controlled and kept to perfect time-keeping by the standard master clock on the firm's stand on the ground floor.

This clock is 60 ft. in diameter. The minute hand measures 30 ft. from centre to tip and the tip of this hand travels just over 18 in. for each half-minute impulse received from the master clock, or just over 3 ft. per minute.

It is interesting to note that the tip of the hand, during the five-day period of the exhibition will travel approximately 3¾ miles. The movement is electrically wound once an hour and is electrically released every half-minute by the master clock. The total current consumption required to operate the dial is less than a third of a unit a day.

Friction and Titanium

ONE OUTGROWTH of the wider use of titanium is the demand for better methods of lubrication where the metal is in sliding contact with itself or other metals. Under such conditions, conventional liquid lubricants allow titanium to seize and gall. While halogenated hydrocarbons and simple halogen compounds reduce galling somewhat, more effective methods of lubrication are required.

According to metallurgists of the Battelle Memorial Institute, research has shown that the problems can be partially overcome by modifying the surface of titanium and lubricating that surface. Studies summarised by the Defence Metals Information Centre indicate that the application of metal coatings appears to be the best solution for seizing and galling, because the friction and wear are removed from the titanium itself. Of the more than a dozen metals that have been studied, nickel coatings have proved to be most effective. The most effective non-metallic coatings now available appear to be cyanide, nitride and fluoride compositions.

Supersonic Wind Tunnel

THE AIRCRAFT RESEARCH ASSOCIATION at Bedford is now operating a £130,000 supersonic wind tunnel capable of reproducing speeds of 1·4 to 3·5 times the speed of sound. A possible extension of this operating range of up to Mach. 4 (about 3,000 m.p.h.) is contemplated.

The new tunnel, which ran for the first time last November, has a working section 2½ ft. high by 2¼ ft. wide and can be used for testing models of up to 2 ft. in length. The compressor which drives it has eleven stages with a total power of 13,780 h.p. The tunnel can be used for missile aerodynamic tests as well as for aircraft work and, as the association points out, "covers a Mach. number range which is going to be used for transport aircraft in the future".

The new facility and the large, transonic tunnel opened three years ago are both available for use by other countries, a number of which—notably Germany, Italy, Japan and France—have shown interest.

Already a certain amount of work on the proposed British supersonic transport, for the study of which a group of companies was announced in January, 1957, has been undertaken. Other work will include missile configuration and air intake tests and, in addition, a study of the effect of jet effluxes on rear structures.

Longevity of Worm Gears

DESIGNERS are usually reticent about committing themselves to stating an expected life for engineering equipment, because accelerated tests do not simulate precisely the real conditions of a natural lifetime and operating conditions also have a large influence.

It is interesting, therefore, to hear from David Brown Industries Ltd. of sixteen worm reduction gears which are still operating satisfactorily after thirty-one years' service. The gears were supplied to James Ferguson & Sons Ltd. in 1927 for driving rolls used in the crumbing of rubber for the manufacture of ebonite. The units are of 17-in. centres and were built before the standardisation of the involute helicoid. The worms are of 15 deg. pressure angle straight-sided linear section and have three threads. The wormwheel rims are of phosphor bronze and have forty-three teeth of 2¼-in. circular pitch. Each gear transmits 40 h.p., reducing the motor speed from 720 to 50 r.p.m., and the duty is heavy and vibratory in character with peaks at irregular intervals depending on hand feeding. While no records are claimed for this performance, it is clear indication of the benefit of good design, for operating conditions can hardly be described as easy.

PICTURE NEWS

IN THE WORLD OF MATERIALS & DESIGN

ELECTROSTATIC GENERATOR

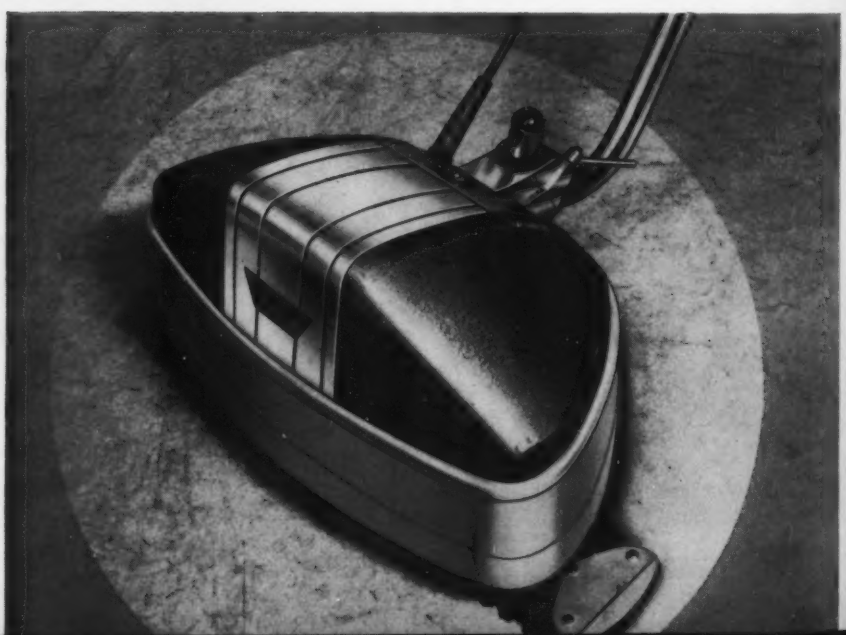
In this six-million volt electrostatic generator for the U.K.A.E.A. at Aldermaston a continuous non-conducting belt of rubberised cloth carries an electrostatic charge from the bottom of the machine to the polished dome at the top. Constant energy beams of particles produced in the generator are used to bombard different materials.

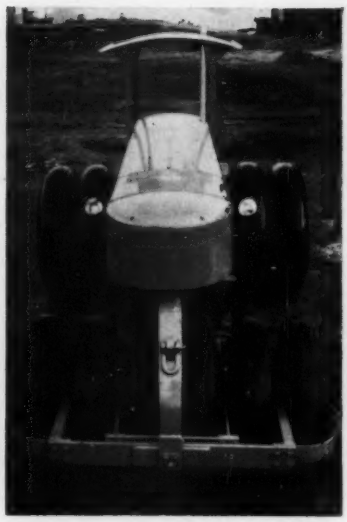
TUNGSTEN COATING

Nose cone for a missile is given a heat-resistant tungsten coating with the new Linde Plasma Arc Torch. Developing between 8,000 and 15,000 deg. C., it can be used to apply coatings or fabricate shapes. Ear muffs give protection from the high-pitched noise of the torch.

FLOOR CLEANER WITH ELLIPTICAL ACTION

Rectangular cleaning elements moving in an elliptical path are able to reach right up to walls and into corners and are also said to eliminate centrifugal force—and thus side-splashing—in the Turmix all-purpose floor machine which is now on the market. It is said that five operations—sanding, scurfing, scrubbing, waxing and polishing—can be carried out by unskilled labour.



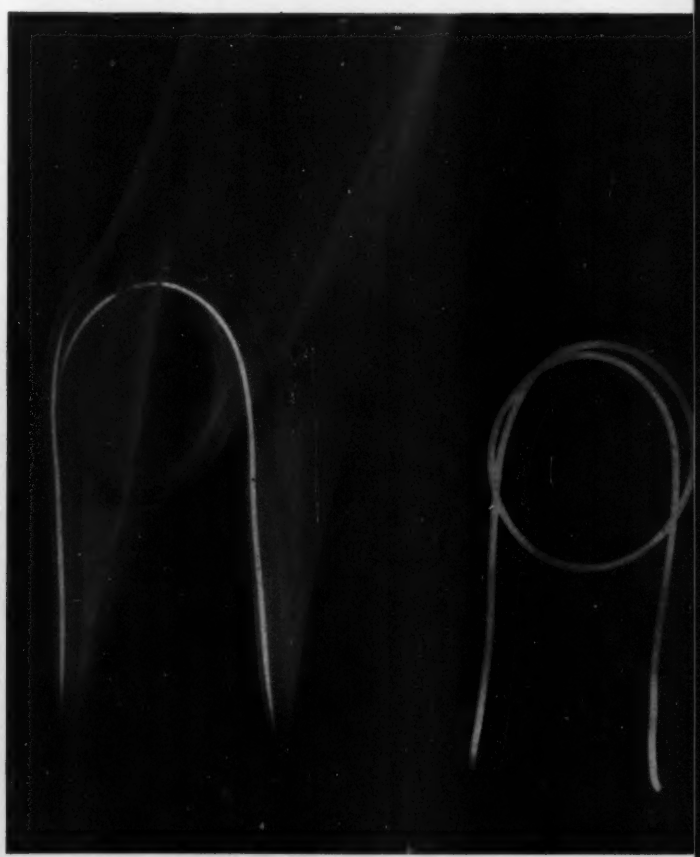


RUBBER-TYRED ROAD ROLLERS

Two German firms have recently produced different versions of pneumatic-tyred road rollers. Left is the GVW-Sonthofen thirteen-wheeler. Right is the Hagelstein Kemna, with ten wheels. They are designed for kneading and compacting in road consolidation work.

REACTOR TIERS IN CONCRETE

This cast-in-concrete reactor tier is one of three supplied by British Thomson-Houston Ltd. to the G.E.B., Amsterdam. These reactors are the largest of this design yet built at the company's Rugby works. Concrete is used because of its robustness and fireproof qualities; it is unimpaired by age and the windings will not become distorted.



SILICON-COATED MOLYBDENUM WIRE

In tests made at the Battelle Memorial Institute in the U.S.A., molybdenum wire coated with silicon (right) showed remarkable resistance to heat, while an uncoated but otherwise similar wire ignites.

Molybdenum Castings

WHAT IS BELIEVED to be the first molybdenum casting has been produced by American scientists at the Bureau of Mines Laboratory in Albany, Ore. Hitherto attempts to cast this metal have been unsuccessful because of its very high melting point (over 2,600 deg. C.), its great reactivity with oxygen and the fact that in the molten state it destroys the crucible. The successful casting recently reported was a cylinder 4½ in. in diameter and 8 in. long, weighing 30 lb. It was produced by melting the metal with a high-density electric arc in a water-cooled copper-lined crucible using an inert atmosphere. The molten metal was then poured into a rotating graphite mould.

This development will be watched with great interest as molybdenum is one of the few metals which retains its strength and structure at high temperatures, and the development of casting techniques may open up new possibilities for cheaper methods of production as well as giving the engineer greater flexibility in design.

Drilling High-alloy Steel

THE U.S. ARMY'S use of carbide-tipped gun drills for drilling stationary work-pieces of high alloy steel has resulted in great savings, according to a report by the Department of Commerce.

One of the outstanding features attributed to this drilling technique is that potentially any component, regardless of size, can be gun drilled. The report states that it is possible to produce a hole in one pass that will have less than 0·002 in./ft. run-out, a diameter within 0·0005 in. of the prescribed dimension, and a surface finish smoother than 16 micro inches.

In some operations, according to the report, as much as a 50 per cent savings in machining time alone was realised, with additional economy in tooling and maintenance costs.

Tantalum for Gradient Furnace

THE NATIONAL BUREAU OF STANDARDS is making use of an unusual type of furnace which readily provides steady temperature conditions between selected temperature limits. Simply constructed to any desired size, this furnace appears applicable to most processes that require a temperature gradient.

The furnace was designed for use in preparing thin metal films of different average-crystallite size, which are used to study electron scattering. As these films are deposited by vacuum evaporation on rock salt crystals heated to various temperatures, a compact, simple furnace was needed. The resulting device is finding wide application. For example, it is being considered, with suitable adaptations, for measurements of the thermoconductivity of metals at very high temperatures as part of the bureau's building technology programme.

The furnace consists essentially of three tantalum strips, spot-welded together in the form of an "H". The model used in crystal growing work has a crosspiece 4 in. long, ½ in. wide and 0·005 in. thick; the legs are 3 in. long, ½ in. wide and 0·01 in. thick. Thermocouples for temperature measurements are placed at various points along the crosspiece between the legs of the "H", which are heated by separate 150-amp. 10-volt transformers. The heating current for this arrangement will maintain either end of the crossbar at any selected temperature between room temperature and 900 deg. C.

The size of the "H" furnace can be modified to fit any particular application, and temperature limits can be extended in both directions. Tantalum will withstand temperatures from the liquid-nitrogen range up to 2,000 deg. C.

Hour tests at temperature differences as great as 500 deg. C. have shown that temperature remains constant to 1 deg. Such steady temperature conditions are rapidly attained because the furnace has a small mass compared to the available electrical power and outgassing from components is negligible. Although the temperature distribution is not linear, this causes no difficulties, for the temperature can be directly measured at any point along the bar.

IN NEXT MONTH'S ISSUE . . .

Principal features in the April issue of

ENGINEERING MATERIALS AND DESIGN will include:

Properties and Uses of Magnesium
Design and production with magnesium-based alloys.

Noise—its Nature, Behaviour and Reduction
First of two articles on its characteristics and elimination.

Asbestos in Modern Railway Service
Old-established and recent applications of the material.

Bonding with Thermoplastic Adhesives
Bonding techniques, testing and inspection.

Belgian Polyethylene

A VENTURE for the manufacture of polyethylene in Belgium has been disclosed with the formation of a new company, Cobenam S.A., owned jointly by Union Carbide International Co. and the Belgian company, Petrochim.

Plans call for the construction of a plant near Antwerp, having an initial capacity of thirty million pounds of polyethylene annually, starting in mid-1960.

This represents the third Union Carbide investment in European polyethylene production, the other two being at Grangemouth (Scotland) and in Sicily.

Rhenium in Electrical Contacts

CONTACTS made of rhenium, tungsten and of their alloys have recently been tested in the U.S.S.R. to determine the effect of humidity, high temperatures and contact arcs on corrosion, erosion and the formation of non-conducting films. Specimens of dense and porous rhenium and alloys of rhenium and tungsten were used for the tests, which were made at the Institute of Metallurgy.

As a contact material, rhenium showed properties approximately equal to those of tungsten. The main advantages of rhenium were shown to be higher resistance to atmospheric corrosion and preservation of contact conductivity under the effect of high temperatures and contact arcs. Rhenium is easily impregnated with silver and copper and can serve as the basic component for contact compositions. Contacts made of rhenium and its alloys are easily soldered to copper, brass and steel mountings. Mechanical cutting and polishing of contacts made of rhenium are performed by the technology applied in tungsten contacts.

Contacts of tungsten-rhenium alloys have properties ranging between those of rhenium and tungsten. It is suggested that rhenium and alloys with tungsten may be more suitable in certain cases where tungsten contacts are at present used.

Bearing Tester

IN DESIGNING SLEEVE BEARINGS it is important to avoid conditions which will allow the oil film between the shaft and the bearing to break down. A precise method of investigating the performance of bearings of various types has been developed by the C.S.I.R.O. at the University of Melbourne.

A unique testing machine has been built for this work. Loads of up to a ton can be applied to bearings and the friction measured with great accuracy. The loads are applied through a metal frame arranged so that the bearing can turn freely even when fully loaded. The measurements are made by balancing the frictional drag of the bearing with small weights hung on an arm attached to the frame. The six pivots in the frame had to be designed so as to be virtually frictionless.

For the first time, "crossed flexure pivots" have been used in equipment of this sort. Flexure pivots have been developed in the last twenty years for many applications where considerable strength is required in a flexible joint.

The C.S.I.R.O. experiments have provided valuable information on the requirements for satisfactory operation of bearings. They have shown the extent to which performance is affected by the quality of the surface finish and the accuracy of shape of the bearing and shaft. The equipment also makes it possible to compare the performance of different bearing metals and lubricants. For example, tin Babbitt bearings have been found to run-in more rapidly than cadmium-silver bearings and therefore to be less liable to seizure. The tendency to seize was also reduced when a solid lubricant, molybdenum disulphide, was added to the oil.

MACHINE TOOL DESIGNERS OF THE FUTURE

BRITAIN'S output of machine tools is not particularly impressive when merely quoted as an annual figure of £100 million, which represents little more than one-half per cent of our total manufacturing output. Yet the importance of the machine tool trade is out of all proportion to the value of its production, since it provides the master tools and equipment with which all engineering industries manufacture their products. In turn, the engineering industries supply the plant and equipment necessary for the whole of industry.

Britain has in the past played a leading part in the design and development of machine tools, but in the last few years there have been signs that other countries such as the U.S.A., Russia and certain continental countries have competed successfully by building up their machine tool industries, and their success is attributed largely to their progressive outlook on design. They are now treating this important subject as a science instead of a practical art. In this country, development often takes the form of improvements on old designs rather than the creation of new ones and some British manufacturers have taken the attitude that as their existing designs are well suited to their jobs, why change them? Continental importers have criticised British machine tool manufacturers on the grounds of technical conservatism, long delivery dates and high prices, but of these points the first is the most serious.

Machine tool design is often extremely complicated, and some of the machine tools operating in modern factories are the result of years of experience culminating in improvements made a few at a time until the final machine bears little resemblance to the original. This process is necessarily slow and in any case cannot meet present-day demands. There have been many new and difficult problems to face but, in order to meet export competition, quick solutions have to be found. There is now no time to build up years of experience but a new and fundamental approach must be made from first principles.

This is not to be taken as a criticism that British methods of development are wrong, but simply that they do not go far enough. Practical experience is essential for all branches of engineering, but it should be based on a fundamental understanding of the principles involved. In order that our machine tool industry can face the future with confidence, it will be necessary to review its methods and train men in fundamental principles of machine tool design in a similar manner to the way academic training is given to recruits in many other branches of industry. It is only recently that machine tools have been considered as coming within the range of academic teaching in this country, although Germany first established a Chair of Production Technology in Machine Tools over fifty years ago. Russia is also very much alive to the importance of co-ordinating machine tool research with the work of the universities which are training machine tool designers.

Dr. H. A. Thomas, in his recent Faraday Lecture, said: "The prosperity of nations has always depended primarily on the industry of their peoples.... Those nations making the fullest use of scientific discoveries have prospered and their peoples now enjoy a higher standard of living. During the past decade new techniques have arisen which are now making the advance so rapid that the term 'Second Industrial Revolution' can justly be applied."

He then went on to show how in the first Industrial Revolution man's physical strength was augmented by power-driven machines, whereas in the second Industrial Revolution his senses are being aided by electronics and his brain by automation. The automatic control of machine tools involves more than merely the addition of electronic equipment to an existing machine, because in order to design an automatic machine tool there must be a thorough understanding of the basic principles of automatic control, electronic sensing, gauging and sorting, subjects which have hitherto been considered right outside the scope of the machine tool designer.

An important announcement relating to the long-term development of the machine tool industry is that ten scholarships, each worth £500, are to be awarded every year by the Machine Tool Trades Association to inaugurate an advanced course in machine tool design at the Manchester College of Science and Technology, beginning next September. For the past three years the department of mechanical engineering at the College has been studying problems of machine tool design. Dr. B. V. Bowden, principal of the College, has recently referred to this work which is actively supported by the National Research Development Corporation. He has explained that their investigations have proved to be tedious, difficult and expensive, calling for the closest possible collaboration between scientists, engineers and craftsmen. It is encouraging to see that this work has been started, but it is vital to the future prosperity of the machine tool industry and of great importance to the country as a whole that this work should be adequately supported by industry. It is to be hoped that the lead shown at Manchester will be closely followed by other teaching institutions so that future designers will be trained to uphold the prestige which the British machine tool industry has commanded in the past.

RESIN-BONDED FABRIC BEARINGS

Substantial power savings and reduction in shaft wear are possible with reinforced-fabric bearings and bushes used under the right conditions. Their potentialities and limitations are discussed in this article

by P. H. PINCHBECK, B.Sc., Ph.D., A.R.I.C.*

RESIN-BONDED fabric bearings have been used in the steel-rolling industry for over twenty-five years and are now being introduced for many other applications. During this period continuing improvements have taken place in resins, reinforcements and manufacturing techniques, and fabric bearings are now regarded as reliable and reproducible engineering materials possessing unique and valuable properties.

The principal stages in their manufacture are as follows:

1. Woven cloth or chopped fibre is impregnated with resin.
2. The impregnated cloth or fibre is formed on, or in, a mould.
3. The resin is caused to set or "cure" by the application of heat and pressure or by chemical activation.
4. The solid form is removed from the mould and machined to the required final dimensions.

The resins employed are of the thermosetting type and consist of chains of recurring molecular units which are cross-linked during the curing stage to form three-dimensional polymers of high molecular weight. The cured resin thus provides a solid, continuous matrix containing embedded fabric. Thermosetting polymers, when reacted in this way, do not soften on subsequent heating and hence form a chemical group distinct from the purely linear or thermoplastic polymers.

In recent years considerable progress has been made in understanding the mechanism of bearing friction and lubrication and it is interesting to examine the properties and performance of fabric bearings in the light of this new knowledge.

MECHANISM OF FRICTION—It has been shown[1, 2] that, even on highly polished metals, surface irregularities are large in relation to molecular size. When two surfaces are brought together the area of contact is not determined by the overall area of the surfaces, but occurs by point contacts between the greatest surface asperities. At such point contacts intense pressures are generated by very small total loads causing plastic deformation of the softer surface and an increase in the area of contact until it is just sufficient to support the load. The true area of contact is thus dependent on the total loading and the physical characteristics of the surfaces involved and is independent of apparent contact areas.

When one surface is moved over another, the work of friction, related to the very small contact areas, results in extremely high surface temperatures. Transient hot spots with temperatures in excess of 1,000 deg. C. have been detected[3] and in cases where one surface has a low thermal conductivity such hot spots occur even more readily.

Slow-moving or static surfaces form cold welds at the points of high pressure contact and at higher speeds temporary welding is assisted by the softening or melting at high spots on the surface layers. Much of the work necessary to slide one surface over another is considered to be due to the shearing of these micro-welds, which are constantly being broken and re-formed. The physical wear of bearing surfaces is also believed to be the result of this weld-breaking, which removes metal from the softer surfaces.

These phenomena explain the classical laws that:

1. The frictional force is proportional to the applied load; and
2. The frictional force is independent of the area of the surfaces in contact,

for, true area of contact $A = \frac{W}{p}$

and force of shear $F = As$

$$\therefore F = \frac{sW}{p}$$

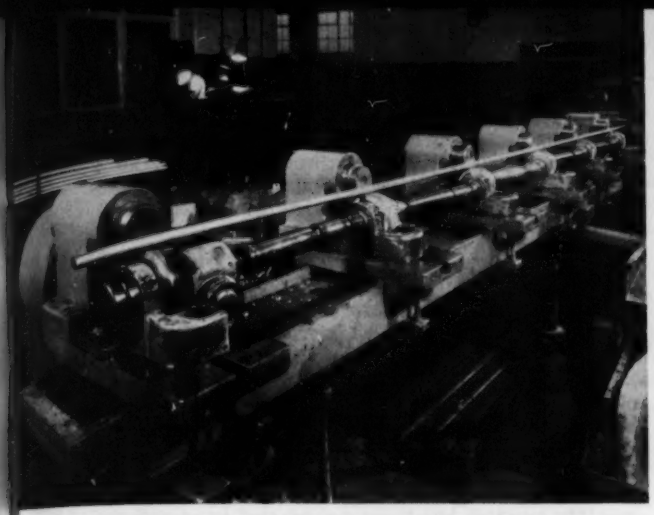
where W = applied load; p = yield pressure of surface; and s = mean tangential stress of shear.

Thus F is proportional to W for a given system, i.e., constant values of s and p.

SURFACE POLISHING—Based on the foregoing, Bowden and Hughes[4] have derived a theory to the effect that polishing is due to the softening and "smearing" over of surface high spots into the lower surface areas, resulting in more even and rounded surface contours. The smeared metal rapidly solidifies on the cooler areas, producing a layer having less crystalline properties and known as the Beilby layer.[5] Experiments have confirmed that the effectiveness of a polisher on a given surface depends more on the relative melting points than on relative hardness. Thus Wood's metal (M.pt. 75 deg. C.) can be polished by the softer material camphor (M.pt. 178 deg. C.), and zinc oxide (Mohs hardness 4) readily polishes the lower melting point but harder material, quartz (Mohs hardness 7).

It was discovered during these experiments that surface flow and polishing may also take place well below the melting point of a metal surface. This is not necessarily inconsistent with the theory of surface flow polishing for, provided the surface temperatures reach a point at which the mechanical strength of the surface is sufficiently low

* *United Coke & Chemicals Co. Ltd.*



A series of bar steady rolls made of fabric.

Fabric conveyor rolls under heavy-duty conditions in an ore mine.

for it to yield under the applied load, a slow polishing action can be expected.

LUBRICATION—The function of a bearing lubricant is to separate the moving surfaces and consequently to reduce friction and wear. Two distinct conditions of lubrication occur and are known as "fluid film" and "boundary" conditions. These states are readily distinguished from a plot of the dimensionless group $\frac{ZN}{P}$ against μ

where Z = Viscosity of lubricant at operating conditions;
N = shaft r.p.m.;
P = projected bearing pressure; and
μ = coefficient of friction.

Fig. 1 shows the typical shape of the $\frac{ZN}{P}$ curve.

Under fluid film conditions the lubricant film is continuous and is caused to flow by the rotation of the shaft; convergence in the clearance space causes hydrodynamic pressure to develop in the film which then supports the load on the shaft. The controlling variables for a particular bearing, as shown by the ZN/P relation, are lubricant viscosity, shaft loading and shaft speed. In fluid film bearing design the most important features are bearing arc, length to diameter ratio, shaft clearance and clearance space configuration. (Under theoretical fluid film conditions of lubrication it will be seen that there would be no contact between bearing surfaces and hence no bearing wear could occur. In fact it has been shown[6] that, under "practicable" fluid film conditions, some contact of bearing surfaces, though infrequent, still takes place.)

The majority of bearing applications, however, do not operate in the fluid state, and surface behaviour under less favourable conditions must be considered. When shaft speeds are low or loads are high (resulting in sufficiently low values of ZN/P) the lubricant does not flow and the bearing surfaces are separated by a thin, often discontinuous, film through which surface irregularities protrude. Unlike fluid film conditions (where the resistance to motion is due only to the lubricant viscosity), friction is now influenced by the nature of the surfaces concerned and the behaviour of the lubricant in very thin films. When surfaces are moved over one another, under boundary lubrication conditions the true area of contact is not as great as with unlubricated surfaces because pockets of lubricant form and support part of the load, as shown in Fig. 2. The greatest surface asperities do, however, make direct contact, reaching high temperatures which result in the welding and shearing action described earlier. Coefficients of friction under these conditions are much higher than under fluid film conditions although lower than those for unlubricated surfaces.

TABLE 1. Effect of long-chain fatty acid on friction coefficient

Surface metal	Coefficient of Friction	
	Paraffin oil	Paraffin oil + 1 per cent lauric acid
Aluminium	0·7	0·3
Copper	0·3	0·08
Iron	0·3	0·2
Zinc	0·2	0·04

The effectiveness of lubricants under boundary conditions depends primarily on their lateral adhesion, i.e., on how readily the film can be broken down laterally to allow surface contact. Various investigations[7, 8, 9] with lubricating oils have indicated that the best results occur when the lubricant can react with the surface to form strong surface layers; thus small quantities of certain fatty acids or similar materials in mineral or hydrocarbon oils markedly reduce the coefficient of frictions at metal surfaces (see Table 1). This effect is attributed to the reaction of polar substances with the metal surface to form a mat of long-chain molecules which bend but are not easily dislodged by the disturbance of the moving shaft.

Fabric Bearings

To what extent does the foregoing throw light on the behaviour of fabric bearings?

COEFFICIENT OF FRICTION AND RATE OF WEAR—The fact that thermosetting resins do not soften or melt as the temperature is raised has two important consequences. Although contact of surface asperities will lead to hot spots (as with metals), micro-welding between bearing and shaft cannot occur and the rate of wear of both surfaces will be reduced accordingly. If hot spot temperatures are sufficiently high, the asperities of a fabric bearing will char away, leaving a smoother surface and small quantities of carbon which, even in non-graphitic forms, is an efficient solid lubricant. In consequence, less work is necessary to move metal surfaces over such materials and a lower coefficient of friction is obtained.

A second advantage of the thermosetting characteristics of fabric bearings follows from the theory of surface flow polishing which relates polishing effectiveness to relative melting points. The thermosetting behaviour, reinforced by the low thermal conductivity of these materials, should result in the slow polishing of metal shafts or journals running in fabric bearings and thus contribute to the reduced friction already expected.

FLUID FILM LUBRICATION—Fabric bearings have been

TABLE 2. Properties of Orkot resin-bonded fabric bearings

Physical Properties	
Specific gravity	1·25
Compressive strength (flatwise) ...	36,000 p.s.i.
Tensile strength (lengthwise)	10,500 p.s.i.
(crosswise)	7,500 p.s.i.
Shear strength	14,500 p.s.i.
Young's modulus (in flexure)	550,000 p.s.i.
Impact strength (Izod)	3·5 ft. lb.
Hardness (Rockwell M)	110
Thermal Properties	
Thermal conductivity (average) ...	7×10^{-4} g.cal./(sec.) (cm.^{2}) (°C./cm.)
Linear expansion coefficient (20–100°C (per °C.))	
parallel to laminations	$1{\cdot}4 \times 10^{-5}$
right angles to laminations	$7{\cdot}9 \times 10^{-5}$
Electrical Properties	
Insulation resistance (B.S. 972)	30 megohms (average)
Electric strength after water immersion (B.S. 972)	Passes proof of 3 kV.
Electric strength at 90°C. (B.S. 972) ...	Passes proof of 3 kV.
Water Absorption	
B.S. 2966 1 in. thick (24 hr. immersion)	— 0·4 per cent.
(100 hr. immersion)	— 1·05 per cent.

found to give their lowest coefficients of frictions with water lubrication, and values approaching those of roller bearings (0·001-0·003) have been recorded.

The resistance to wear of the bearing material is not of primary importance in the design of fluid film bearings, but performance is critically affected by the choice of lubricant which, in turn, may determine the type of bearing material to be used. Oil-lubricated/alloy bearing systems are commonly used, but there is a strong case for the consideration of water-lubricated fabric bearing systems. The resistance to shaft motion under hydrodynamic conditions is due entirely to the lubricant viscosity, and a comparison of oil and water viscosities at various temperatures (Table 4) indicates that considerable reductions of power losses on high-speed bearings should be obtained if water is employed as a lubricant in place of oil.

Newman[10] in a report on water-lubricated marine turbine bearings draws attention to the fact that, because of the lower viscosity of water, boundary conditions will persist into higher speed ranges than with oil lubrication, but that as the viscosity ratio of oil to water decreases with increasing temperature this disadvantage is reduced as temperature levels increase, i.e., as shaft speed increases.

This author also states that a practical limit exists to the speed at which turbine bearings may be operated. This is governed by the cooling capacity of the lubricant and the lubricant temperature-viscosity relationship. In this respect water possesses major advantages over oil and the limiting speeds should be considerably higher.

BOUNDARY LUBRICATION—Under conditions of boundary lubrication the inherently low friction coefficient and polishing properties of fabric bearings are of first importance. Water lubrication is surprisingly effective under boundary conditions and many years of rolling-mill experience has confirmed the superiority of fabric over alloy bearings under the most arduous conditions. One explanation of this, put forward by Rowell,[11] suggests that the working surface of fabric bearings consists of a forest of microscopic cellulose fibres impregnated with water and holding water between them by capillary action. This theory, analogous to the polar molecule theory with lubricating oils discussed earlier, implies that the fabric: resin ratio affects bearing performance, a result confirmed by practical experience.

Bearing Design Factors

CHOICE OF LUBRICANT—As has already been stated, fabric bearings give excellent performance with water lubrication. It follows, therefore, that aqueous solutions also make satisfactory lubricants provided that the solution does not chemically attack the fibres or the resin, and this fact may often be utilised to simplify bearing design. Fabric bearings have already been operated in a wide range of process liquors, including brine, dilute acids, dilute alkalis, detergents, sewage and solutions of various salts. This method of allowing a process to provide its own lubricant may also be employed with organic liquids which do not attack the bearing material.

Fabric bearings are often operated with soluble oils, oils or greases and the coefficients of friction with such lubricants are usually lower than with alloy bearings, but are, nevertheless, higher than with aqueous lubrication. The higher coefficients are explained by the fact that the fabric fibres are not wetted as efficiently by these lubricants and therefore the protective film produced is broken down more readily.

Table 3 gives the coefficients of friction obtained with one type of fabric bearing and various lubricants.

OTHER DESIGN FACTORS—The designer specifying fabric bearings must take into account other special features of these materials. Table 6 lists some of these important characteristics.

As any cellulose reinforcement is capable of absorbing liquids, it may be necessary to make allowances for the dimensional expansion which occurs when aqueous lubrication is employed. This is especially true in the case of full 360-deg. bearings where significant changes in diameter may occur, the degree being governed by bearing diameter and wall thickness. The absorption of oil and other viscous liquids takes place less readily and dimensional changes under such conditions are usually negligible.

Where operating temperatures are relatively high, allowances may also have to be made for thermal expansion which is slightly higher than that of most metals. In addition, temperature limits for fabric bearings exist and bearing performances may be seriously impaired if used above the manufacturer's recommended maximum.

The thermal conductivity of these bearings is very low compared to metals and, consequently, special provision must be made in hot working conditions for the removal

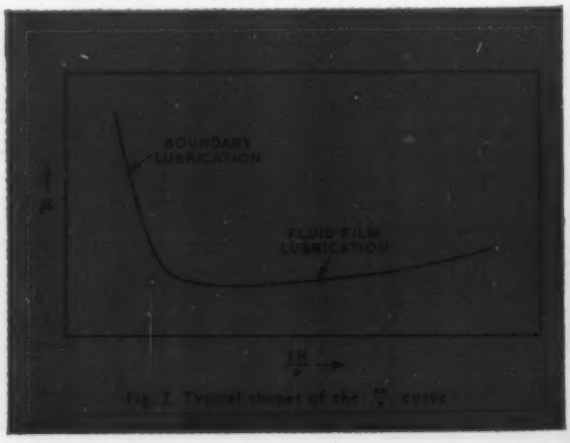


Fig. 1. Typical shape of the $\frac{fn}{p}$ curve

of heat (e.g., excess lubricant). In most cold applications, however, the low coefficient of friction of the bearings compensates for the low conductivity and no build-up of frictional heat is observed.

Rolling Mills

Roll-neck bearings were the first use to which fabric bearings were put and a wealth of experience has been acquired in this specialised field. Conditions vary widely in the metal rolling industry—hot or cold mills, reversing or unidirectional, single or multi-stand, continuous or intermittent, etc.—and it is not proposed to review the subject in detail here. However, roll-neck bearings are normally required to withstand high pressures (2,000 p.s.i. being a common load) at low rubbing speeds—often with heavy shock loading. Although in certain instances fluid film conditions can be achieved, in general (because of dimensional restrictions) boundary lubrication conditions must be accepted and it is in this context that the use of fabric bearings must be surveyed.

The cost of operation of roll-neck bearings per ton of rolled product can be considered under the following headings:

1. Depreciation—based on bearing assembly cost. bearing replacement cost and average life.
2. Cost of lubrication.
3. Cost of power consumed in overcoming roll-neck friction.
4. Cost of product rolled outside gauge limits due to bearing wear.
5. Cost of maintenance, adjustment and replacement delays.

Although the relative importance of these items varies in different mills, certain generalisations will be found to hold good.

(a) Fabric bearings, because they have no scrap value, are generally slightly more expensive than metal alloy bearings but, as considerably increased bearing lives are obtained, they are found to be more economic on a depreciation basis.

(b) Lubrication costs are generally small for both oil- and water-lubricated materials, although in hot mills where adequate supplies of clean water are not available this factor can rule out the use of fabric bearings. Soluble oils are often employed satisfactorily with fabric bearings and at very low rubbing speeds the addition of grease is usually recommended.

Because of the low thermal conductivity of fabric bearings, sufficient lubricant must be supplied to remove the heat generated by friction and also, in hot mills, the heat conducted along the rolls to the bearing assembly. The

TABLE 3. Coefficients of friction obtained with an 18/8 stainless steel shaft running in Orkot bearings. Rubbing speed, 90 f.p.m.; load, 2,240 p.s.i.

Lubricant	Water	Soluble oil	Grease/water	Oil	Grease	Dry
μ	0·006	0·015	0·016	0·017	0·062	0·21

TABLE 4. Relative oil and water viscosities at different temperatures

Temperature	Viscosity (centistokes)		Viscosity ratio (oil/water)
	Typical turbine lubricating oil	Water	
100 deg. F.	64·5	0·68	95
125 deg. F.	35·0	0·54	65
150 deg. F.	20·0	0·42	49

amount of water required to remove frictional heat is given by the expression[12]:

$$\text{Water requirement gal./min.} = \frac{\pi\mu PDN}{53{,}500\Delta t\eta}$$

where μ = coefficient of friction at rolling conditions;
P = bearing load, lb.;
D = bearing diameter, in.;
N = bearing r.p.m.;
Δt = differential between bearing temperature and water inlet temperature, deg. C.; and
η = heat-to-water transfer efficiency (0 = no transfer; 1 = complete transfer).

Data on the value of the factor η which varies with the rolling conditions are not readily available although there are indications that it is generally of the order of 0·5. In hot rolling a further allowance, depending on conditions and mill experience, must be made for conducted and radiant heat.

(c) The power required to overcome roll-neck friction is given by the expression:

$$\frac{\pi\mu PDN}{33{,}000}$$

(the symbols having the same meanings as assigned previously) and thus for a given set of rolling conditions is dependent only on the coefficient of friction between bearing and roll neck.

Typical values of μ for different bearing systems have been quoted, depending on conditions, as:

Roller bearings ... ... 0·001-0·002
Flood lubricated sleeve ... ... 0·001-0·005
Brass, bronze or babbitt ... ... 0·01 -0·15

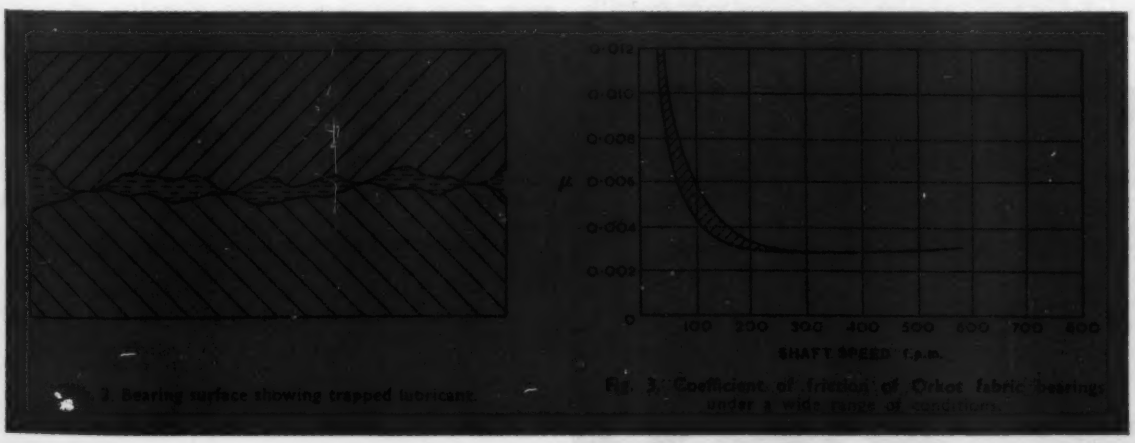


Fig. 2. Bearing surface showing trapped lubricant.

Fig. 3. Coefficient of friction of Orkot fabric bearings under a wide range of conditions.

TABLE 5. Example of economies achieved with resin-bonded fabric bearings (Orkot)

	Bearing type	Lubrication	Average bearing life	Power saving	Saving in bearing and power costs
10-in and 14-in. section mill. Multi-stand, uni-directional hand mill	Phosphor-bronze with white metal inserts	Grease/water	1,165 tons		
	Fabric	Water	10,100 tons	43%	£5,000 p.a.
Bar mill. Multi-stand cross-country merchant mill.	White metal with phosphor-bronze inserts	Grease/water	1,190 tons		
	Fabric	Water	15,500 tons	22%	£6,500 p.a.
28-in. sleeper plate mill. Multi-stand reversing.	Phosphor-bronze with white metal inserts	Grease/water	1,300 tons		
	Fabric	Water	20,000 tons	15% (estimated)	£5,000 p.a. (extensive fire cracking of roll necks also eliminated)

Fig. 3 shows the coefficient of friction of one type of fabric bearing under a wide range of conditions.

The level of power savings possible by a reduction in frictional coefficient may be deduced from an expression suggested by Knight[13] and termed "journal efficiency". This is defined as the ratio of the horsepower required to deform the material being rolled to the total horsepower required to drive the rolls. Making certain simplifying assumptions, it can be shown that:

$$\text{Journal efficiency} = \frac{1}{1 + \sqrt{\frac{\mu D}{R (h_1 - h_2)}}}$$

where R = radius of rolls;

h_1 = thickness of material before pass;

h_2 = thickness of material after pass;

μ and D having the same meaning as under (b) above.

Thus for a given mill the ratio of productive work to total work decreases as the square root of the reduction term $(h_1 - h_2)$ decreases. Or, in other words, the greatest proportional power savings will be possible when sheets or thin sections are being rolled. In clogging, slabbing or heavy section mills the proportion of power used in overcoming friction will be smaller, although, of course, it may well be large in absolute magnitude.

(d), (e) The remaining items in this comparative assessment of rolling-mill bearings depend primarily on the rate of wear of the bearing. In rolling mills this is often subject to extraneous factors such as roll-neck condition, entry of scale or dirt with lubricant, lubricant supply failure, roll or bearing misalignment, etc., and bearing performance can be reliably assessed only from the average of a number of trials. Although performances vary greatly in different types of mills, information available[14, 15] suggests that fabric bearings can be expected to give between two and ten times the life of alloy bearings.

A further factor which might be considered under maintenance is the fire cracking of roll necks. High neck friction has been found to cause thermal stress leading to cracks in the roll neck. Such cracks increase both wear and friction and may eventually lead to actual fracture of the roll neck. The use of water-lubricated fabric bearings avoids this trouble and thus reduces the cost of maintenance and replacement of rolls.

To illustrate the advantages which have been obtained in practice from the use of fabric bearings in certain rolling mills, Table 5 gives representative figures taken from the records of The United Steel Companies Ltd. over a period of several years.

Bushes and Bearings: General Uses

Bushes and bearings are used in every branch of the engineering industry and the conditions encountered vary even more widely than in the rolling of metals. Loads vary from a few pounds to tons per square inch, sometimes with high shock loadings, and rubbing speeds from hundreds of feet down to a few inches per minute with continuous or reversing movement. Lubrication available may be water, sludges, detergents, chemical solutions, acids, alkalis, soluble oils or grease, while lubricant supply of whatever nature, is often intermittent.

It frequently happens that the wear of the journal, shaft or pin which moves in the bush is of greater importance than the wear of the bush itself: nevertheless, longer lives are required from most bushes than from rolling-mill bearings.

POLISHING EFFECT—Power losses are not usually significant with bushes and the very low coefficients of friction obtainable with fabric bearings are therefore of direct importance only in so far as they reflect a low rate of wear. More important is the polishing effect of fabrics on the shaft or journal concerned, which maintains the low rate of wear at both rubbing surfaces. (An illustration of this was obtained in one recent test when case-hardened steel bushes in an articulated vehicle trailing axle were replaced by Orkot bushes. The bushes, operating under a dead weight load of about 1,800 p.s.i., were subject to shock loading, and an automatic oil lubricant supply was fitted. After 80,000 miles of vehicle operation the bushes and pins were removed for examination. No wear was measurable on the pins which had acquired

A group of fabric bearings, indicating the complexity of shapes that is possible.

polished surfaces and wear of the order of 0·001 in. was measurable on the bushes being used. Normally both pins and bushes required replacements after this mileage.)

LUBRICATION — The versatility of certain fabric-reinforced materials as regards lubrication renders them suitable for many applications where bearings have to operate immersed in process solutions. The materials do not corrode and are resistant to most chemical attack.

Transfer Roll Coverings

The metal rolling industries use large numbers of transfer rolls, which guide or carry the material concerned through various processes. These rolls may be powered or free running and are frequently made of cast iron. The loads involved are small, but a common source of trouble has been the over-running of the rolls when the material (especially strip or sheet) is halted, causing marking or scratching of the surface and leading to substantial wastage.

Transfer rolls can be covered simply and economically in Orkot, and excellent bonding between the metal and the fabric-reinforced resin can be achieved by manufacturing and curing the coating on the metal rolls themselves. Such rolls are easily repaired or re-covered when necessary, while the use of existing rolls as a core ensures that the completed item, and more particularly the roll necks, have adequate strength for the job.

Because of its simplicity, this application finds uses in many industries. Stainless steel, tinplate, aluminium and other non-ferrous metals are all subject to scratching by transfer rolls; textile, dyeing, paper manufacturing and printing industries also use large numbers of rolls often in contact with aqueous solutions, and in any application where marking or damage of the product by transfer rolls must be avoided the use of fabric coatings can lead to considerable savings.

Fabric Rolls

In some situations weight savings may be essential or desirable because of the design of the roll supports. Rolls made from fabric-reinforced resin cylinders and spacing discs on small-diameter metal shafts have proved satisfactory in such cases and weight savings of the order of 75 per cent have been realised.

A particularly interesting recent development has been in tramp iron detection gear on conveyor belts. Detectors operated by strong electric fields are disturbed by the moving metal rolls supporting the belt in the vicinity of the field. Bonded fabric rolls, because of their non-metallic character, were found to eliminate interference of this nature and gave satisfactory lives.

OTHER USES—Applications of these materials, several of which are still in the testing stages, include stripper plates for strip mills, coupling pads, slide blocks, pump

Strip transfer rolls coated with Orkot.

piston rings, worm wheels, thrust pads, insulating jackets, sealing rings, turbine bearings, railway wagon bearing pads, cage guide blocks, gland and neck rings, pump swivel pins, vacuum box covers, valve components, rod and bar reeler guides and many other uses.

CONCLUSIONS—The behaviour of fabric-reinforced bearings, predictable from modern theories of friction and lubrication, is amply borne out in practice. Low frictional coefficients are obtained even under adverse conditions and substantial power savings can be achieved in large-scale applications. In many cases shaft wear can be virtually eliminated and the polishing effect and low frictional coefficients associated with fabric bearings contribute to their excellent wearing properties.

To balance the picture the disadvantages of these materials should be kept in mind. A capacity to absorb lubricants, particularly water, leads to some dimensional instability which may become critical, particularly in 360-deg. bearings. The thermal expansion, which is higher than that of most metals, may necessitate design allowances in cases where the bearing assembly has to operate at elevated temperatures. Also, as the thermal conductivity of fabric bearings places them almost in the thermal insulator class, means of dissipating any conducted and radiated heat must be incorporated.

Taking due account of these points, it remains true that the engineer has to his hand a relatively new, economic and reliable choice of materials with remarkable potential uses. Moreover, he is assured of continual improvements in performance for many years to come by virtue of the continued and vigorous development of the synthetic resin industry.

TABLE 6. Special design features of fabric bearings

Property	Typical values for fabric bearings
Water absorption of 1 in. thick laminate (24 hr. immersion)	0·1–0·5%
Linear expansion coefficient per °C. × 10^5	
Parallel to laminations	1·0–2·5
Right angles to laminations	3·0–9·0
Thermal conductivity C.G.S. units × 10^4	5·0–20·0
Temperature limitations in use	100°–200°C.

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PALLADIUM-CONTAINING ALLOYS FOR HIGH-TEMPERATURE BRAZING

New techniques in high-temperature brazing have been developed in the past few years. This article indicates how the addition of palladium to some established filler alloys can result in improved brazing quality

by E. R. PERRY*

HIGH-TEMPERATURE brazing may be defined as a method of joining metals in which a molten filler alloy having a melting point above 800 deg. C. freezes in the space between closely adjacent surfaces of the parts which are to be united. Ideally, the filler material (brazing alloy) should possess corrosion-resistance and high-temperature strength properties similar to those of the metals it is joining.

There are many cases where strong permanent joints are necessary, but where welding or riveting is not a possible method of fabrication. High-temperature brazing may, however, be suitable since joints made by that method, if correctly designed, usually have strength adequate for such purposes. For instance, tests[1] indicate that at 800 deg. C. brazed joints in Nimonic 90 can be expected to have a static shear strength of from 35,800 to 42,500 p.s.i. (depending on the brazing alloy used) and a stress-to-rupture life of more than 1,000 hours at 4,480 p.s.i. Other considerations which commend high-temperature brazing may also be mentioned, for example:

(a) Different metals may thus be joined together, e.g., Monel to beryllium or to copper.

(b) Very thin materials, e.g., 0·002 in. thick, may be joined, as in the manufacture of honeycomb structures or heat-exchanger components. In such applications, however, inspection difficulties may arise due to the complex nature of the joints involved, the geometry of which may be such that radiographic examination is not entirely reliable.

(c) It is relatively easy to control the quality of correctly designed joints and to ensure consistency in large-scale production. Once the optimum operating conditions are established, brazing can be carried out by automatic and semi-automatic processes, with consequent economy in use of skilled labour. Attention to the position of the brazing alloy, the gaps (clearances) between the parts to be joined, the stress-relief treatment of the parts before final machining and brazing, the effects of any variations in section of members, the method of jigging the parts, and adequate venting of the joints are all vital considerations.

(d) By pre-placing brazing alloy, it is possible to make joints at positions which would be inaccessible using many other methods of assembly.

(e) In brazing, the heat required may be applied by a number of methods (salt baths, electrical heating, oxy-gas torch, etc.) Irrespective of the method used, care should be taken to prevent internal stresses which would result from non-uniform heating, and it is important also to avoid movement, which may cause misalignment of com-

TABLE 1. Palladium-containing brazing alloys

Alloy (% Composition)	Liquidus (°C.)	Solidus (°C.)	Brazing Temp. (°C.)
SPM1 (Ag 75, Pd 20, Mn 5) (Baker 2601)	1,120	1,003	1,120
SPM2 (Ag 64, Pd 33, Mn 3) (Baker 2602)	1,200	1,180	1,220
NMP1 (Ni 48, Mn 31, Pd 21) (Baker 318)	1,120	1,120	1,125
SCP1 (Ag 68·4, Cu 26·6, Pd 5) (Baker 722)	810	807	815
SCP2 (Ag 58·5, Cu 31·5, Pd 10) (Baker 723)	852	824	860
SCP3 (Ag 65, Cu 20, Pd 15) (Baker 724)	900	850	905
SCP4 (Ag 54, Pd 25, Cu 21) (Baker 725)	950	901	955
SCP5 (Ag 95, Pd 5) (Baker 718)	1,010	970	1,015
SCP6 (Cu 82, Pd 18) (Baker 719)	1,090	1,080	1,095
SCP7 (Ag 52, Cu 28, Pd 20) (Baker 748)	898	879	905
PN1 (Pd 60, Ni 40) (Baker 288)	1,237	1,237	1,250

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ponents before brazing, with consequent alteration in the clearances allowed in designing the joint.

(f) Brazed joints usually require little or no subsequent machining.

Recent Progress

During the past decade considerable impetus has been given to the development of high-temperature brazing techniques, particularly in connection with the need for materials suitable for joining gas-turbine blading. The technique has been investigated, *inter alia*, as a means of attaching root fixtures to extruded Nimonic blading which contain cooling holes, and it has been used also for joining sections of turbine blades in which cooling passages are first prepared by machining.

In the course of investigations on brazing alloys it was observed, in the research laboratories of the Mond Nickel Co., that the addition of palladium to certain established types of filler alloys (copper, copper-silver eutectic and 85 per cent silver-15 per cent manganese alloy) is accompanied by marked improvement in brazing quality, corrosion-resistance and strength of alloys. Following this discovery, the company has developed a range of palladium-containing alloys for joining nickel-base alloys both to themselves and to other materials, including cupronickel alloys, cobalt-base alloys, steels, gold, molybdenum, tungsten, etc. Table 1 gives details of the compositions, melting ranges and recommended brazing temperatures of the palladium-containing alloys.

The SPM alloys are based on the silver-palladium-manganese and NMP1 on the nickel-manganese-palladium ternary systems: all three alloys were developed primarily for brazing gas-turbine components.

SPM1 alloy is suitable for service in the temperature range 600-700 deg. C.: SPM2 is a stronger alloy, and for many applications is to be preferred, as it may be used at temperatures up to 800 deg. C. When used in joining materials containing as a major constituent an element which is immiscible with a constituent of the brazing alloy, neither of the silver-palladium-manganese alloys should be heated much above the temperatures mentioned. For example, prolonged overheating of a joint in a high-nickel alloy which has been made with a silver-palladium-manganese alloy may result in segregation of a weak silver-rich solid solution at the centre of the joint.

NMP1 is the alloy most recently developed for gas-turbine applications and although the thinnest gauges are not yet available in production quantities, it may, like SPM2, be used at 800 deg. C. NMP1 has the advantage of avoiding dangers due to immiscible phases. Furthermore, this alloy offers good resistance to attack by sodium and the sodium-potassium eutectic and is therefore of interest for joining components which in service will come into contact with liquid alkali metals.

The SCP and PN1 alloys are based, respectively, on the silver-copper-palladium and palladium-nickel systems. In developing these alloys the special requirements of the radio industry were of paramount importance, and less attention has been given to high-temperature properties. In this case the primary aim was to produce a graded series which would permit brazing at different stages in the manufacture of an electronic valve, i.e. step-by-step brazing, and the requirement was also for brazing alloys having vapour pressures lower than those of previously known materials. Apart from these applications, the lower melting characteristics of the silver-copper-palladium alloys have also been used to advantage in brazing components for service at elevated temperatures, notably in cases where the materials to be joined are susceptible to pronounced grain growth if brazing alloys of higher melting point are used. In some instances, by using an appropriate brazing alloy, it has been found possible to

For an experimental Rolls-Royce engine the Nimonic turbine blading was air-cooled. Cooling passages were machined into a root, over which was placed a sheath which was brazed into position with SPM2 alloy.

Components of the astern nozzle box assembly used in the free-piston gas turbine engine of the ore-carrying ship *Auroy* were joined with SCP3 brazing alloy.

Silver-copper-palladium alloys, SCP1 and SCP2, are used in the construction of v.h.f. and other transmitting valves made by Standard Telephones & Cables Ltd.

Beryllium is brazed to Monel with SCP2 in the production of windows for the Metropolitan-Vickers Raymax 50 X-ray tube.

combine the brazing with a heat-treatment operation.

Among the properties possessed by the palladium-containing brazing alloys the following are regarded as most important:

(1) The alloys possess excellent flowing and wetting properties: consequently, large gaps, ranging up to 0·020 in., are possible. It has also been shown that the alloys are capable of penetrating into the spaces between the parts to be joined to a greater depth than is attainable with alloys which do not contain palladium. The fact that permissible joint clearance thus secured is not critical may represent considerable saving in costly machining operations otherwise needed to produce final, close tolerance immediately before brazing.

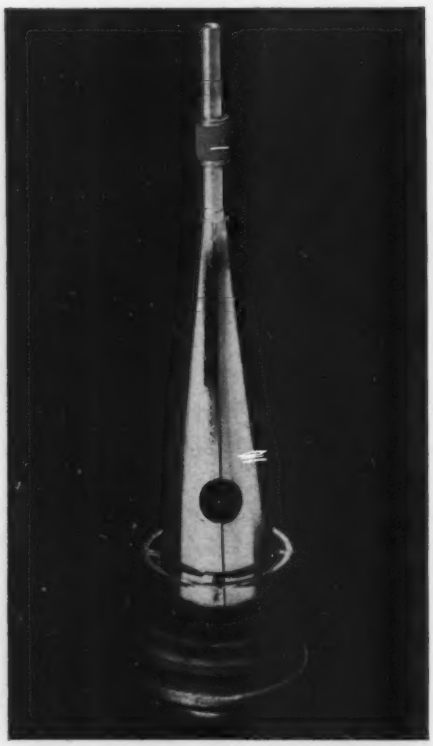
(2) Even when the recommended brazing temperatures are greatly exceeded, there is little attack of the parent metals by the palladium-containing alloys. This is in striking contrast to many alloys which do not contain palladium, where close control of temperature, and use of the minimum amount of alloy which will effect brazing, are vital factors. This difference is particularly significant when joining very thin materials. When joining nickel-containing alloys, including 18/8-type stainless steel, with boron-containing alloys the attack may take the form of intergranular penetration which does not cause rupture at the time of brazing, but may adversely influence the behaviour of the joint in service. It is reasoned that the presence of an intercrystalline film of a hard boride phase in the base metal impairs the mechanical properties of the joint: in room-temperature tensile tests on brazed joints containing these microstructural features Chang has actually encountered embrittlement effects traceable to boride phases.[2]

(3) The majority of the palladium-containing alloys have been found to be ductile and can therefore be produced as foil or wire. Since this ductility persists in brazed nickel-containing alloys, dangers of failure through low ductility at the joints are unlikely. The wire and foil forms are in many ways preferable to powder, as with wire and foil a wider variety of heating methods can be used. On occasion, and according to requirement and convenience, oxy-gas torch, salt bath, muffle furnace (in various controlled atmospheres, such as hydrogen, cracked ammonia, town gas, forming gas), resistance brazing and high-frequency induction coils have been used as heating media. (It is, however, appreciated that there are occasions when a powdered-type filler alloy offers advantages and, to meet this demand, NMP1 has been prepared experimentally in the form of atomised powder.) If the alloys to be joined contain aluminium, titanium or other reactive metals in amounts greatly exceeding 0·5 per cent electroplating prior to brazing (0·0002-0·0004 in. nickel) or fluxing (with boric acid or borax) is advisable. Sometimes electroplating is impracticable, or fluxing is undesirable: in such cases brazing in vacuum is the solution. There is evidence that breakdown of a boron-containing flux occurs if the materials being joined are maintained for prolonged periods at the brazing temperature, and the boron thus released may attack the parent metals. In vacuum brazing, on the other hand, evaporation of silver from brazing alloys which contain this metal can prove a nuisance if a prolonged brazing cycle is employed. In such cases alloys NMP1 and PN1 are preferred.

(4) Step-by-step brazing. By appropriate selection of palladium-containing brazing alloys it is possible to make joints at various stages in the production of complicated components: reference to Table 1 shows that steps of approximately 50 deg. C. in liquidus temperature are available in the range 800-1,100 deg. C. and this range may be extended to 1,250 deg. C. by using some of the other alloys given in the table.

(5) The palladium-containing alloys appear to be particularly suitable for brazing nickel-iron-cobalt alloys such as Nilo-K and other low-expansion materials. When brazed with silver or the copper-silver eutectic, alloys of this type suffer intercrystalline embrittlement, an effect which is especially detrimental if leakage of vacuum is permitted; for example, in radio valves and X-ray tubes. Apparently the addition of palladium to the copper-silver eutectic suppresses this tendency to brittleness, although reasons for the corrective effect are not yet clear.

It is evident from the foregoing that the palladium-containing series of brazing alloys provides a range of materials which will give adequate joints in many alloys destined for service in a wide variety of applications, ranging from radio valves operating at room temperatures to the very severe high-temperature conditions to which the blading of an aircraft gas turbine is subject. The series is flexible with regard to the strength and corrosion-resistance properties obtainable and the technique for making well-filled brazed joints with such alloys is not critical. It is obvious that, since palladium is a precious metal, alloys containing it are more costly than base-metal compositions. In making a brazed joint, however, only a small quantity is used, and where dependability is foremost, as in a turbine blade or a radio valve, the cost of the brazing alloy is small by comparison with the overall sum involved in machining such a component.



PN1 alloy is used to join molybdenum parts in the construction of the cathode assembly of the Mullard JP 250 magnetron.

The palladium-containing alloys are marketed by Engelhard Industries Ltd., Baker Platinum Division, 52 High Holborn, London, W.C.1. The whole series is covered by British Patents (Nos. 573176, 646899, 671072 and 742820).

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1. Beatson, E. V. "The Contribution of Brazing in Light Engineering Design and Processing". Inst. Mech. Eng. Conf. on Technology of Engineering Manufacture, 1958, Paper 26; (see also discussion).
2. Chang, W. H. "Basic Characteristics of Some Heat-resisting Brazing Filler Materials". *Welding Jnl.*, 1956, **35**, 431-43.

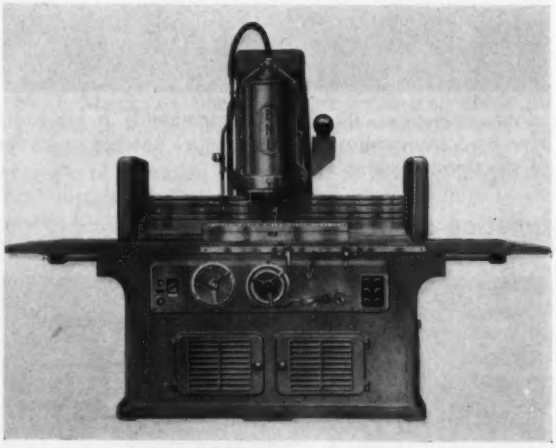
NEW IDEAS IN DESIGN

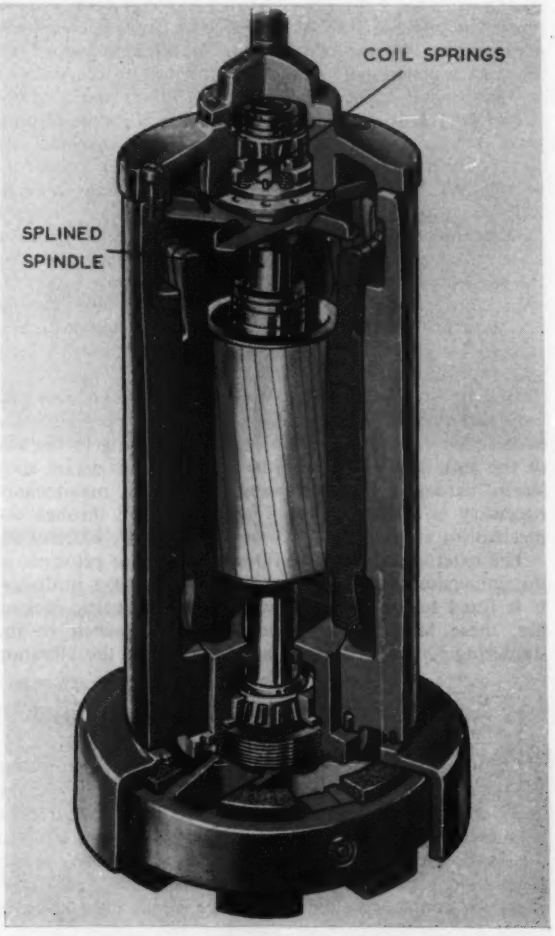
Outstanding products in current manufacture

Automatic Compensation for Heat and Wear in Surface Grinder Spindle

IN the Northrop V.G.2, a new vertical spindle surface grinder for heavy-duty conditions, attention to the design of the integral motor grinding head spindle has resulted in a machine claimed by the manufacturers to be capable of producing surface finishes from 6-8 micro-in. The vertical spindle is mounted in micron precision taper roller bearings. Automatic compensation for wear of the bearings or elongation of the spindle, due to heating up during the running period, is achieved by pre-loaded coil springs which bear against the thrust collar on the spindle and against a ring which bears against the outer race of the upper taper roller bearing. The grinding head has six segments as a normal complement. In practice, however, three segments only may often be used. A high rate of stock removal and efficient use of the abrasive is made possible by a downward feed of the grinding head at each reversal of the table.

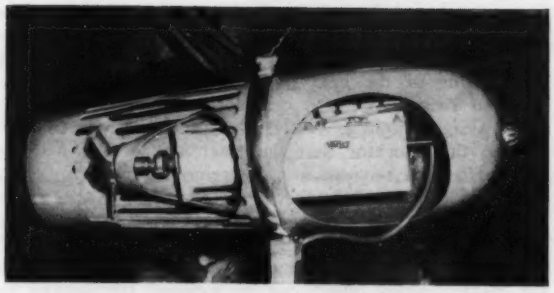
To secure maximum rigidity and precision, the machine beds are cast in one piece, particular attention being given to the elimination of unwelcome stress points. The hydraulic controls are to Northrop design, the emphasis being on simplicity and ruggedness. The table working surface, 30 in. long and 12 in. wide, has a longitudinal traverse of 45 in., the maximum distance between wheel and table being 12 in. The machine is built to Schlesinger's machine tool standards.





Under-water Tug for Skin Divers

GLASS fibre-reinforced plastics have been used for the pressure hull of the Sub-Aqua-Jet, an electrically powered underwater tug built by Tough Bros. The hull is divided into two airtight compartments, the forward one containing two non-spill, heavy-duty, 12-volt, 25-amp./hr. batteries. In the case of the two-battery installation, the batteries are connected in parallel to a 12-volt C.A.V. motor in the aft airtight compartment. The motor is controlled by a simple trigger switch in the right-hand handle. This ensures that if the diver accidentally releases the Sub Aqua-Jet the motor immediately cuts out. The tug is unsinkable.



Concrete Vibrators Use Sliding Vane Rotor

THE Sinex concrete vibrators, which work on a turbo-pneumatic principle, were developed in conjunction with S.T.V. Vibratechniques of Paris. They are intended for compacting very dry concrete mixes as now used.

The immersion vibrator illustrated consists of a control handle for coupling to the main air supply, a 6-ft. length of hose with a smaller diameter central tube and a vibrator head and working mechanism. Within the metal casing of the vibrator head are only two moving parts, a rotor and a sliding vane. The rotor is free to move sideways and eccentrically between two flanges. The sliding vane is fitted in a machined slot in the central spindle, which is drilled to take the air inlet supply to the sliding vane and the rotor. Air forces the vane outwards and, by means of ports machined into one side of the vane slot, displaces the rotor, which moves in an eccentric movement round the spindle. As the rotor moves on its epicyclic path, the vane is forced back into its slot, the exhaust air escaping through holes in the upper flange and thence upwards to exhaust ports in the handle via the annular space between the outer case and the central spindle. When air leaves the space between the rotor and the spindle at the escape side, the vane is once more pushed out of the slot and compressed air is again injected through ports into this area, and the cycle starts again.

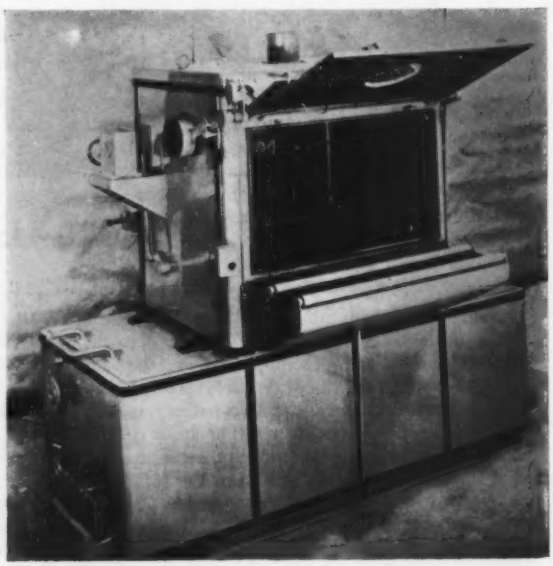
The out-of-balance force produced by the eccentric movement of the rotor causes a high-frequency vibration of between 18,000 and 20,000 c.p.m. according to the size of the unit. The whole vibrator is made from nickel alloy steels, hardened and tempered. The only maintenance necessary is to blow a small amount of oil through the mechanism after use to prevent rust due to condensation.

The external vibrator operates on the same principle as the immersion vibrator and is somewhat simpler in design. It is fitted to brackets by means of an eccentric locking pin, these brackets being permanently attached to the shuttering or moulds. The vibrator transmits the vibration to the concrete via the shuttering or moulds. It can easily be moved from one prefixed bracket to another by means of the simple locking pin.

Pickling, Degreasing and Phosphating Plant in One Unit

BY using a spraying method, all the above forms of surface treatment can be carried out on the Wache single-chamber metal washing or processing machine. The manufacturers claim that the machine is economical, even for small batch production, that from the efficiency standpoint it is superior in that all the operations are automatically controlled, and that there is no carry-over of liquid.

A wire basket containing the work is inserted into the spray chamber. Closing the door operates a stop cock and the pre-set working sequence is commenced. First, the degreasing or treatment pump and rocking gear for oscillating the basket are switched on. At the end of a set time this pump is switched off and the tipping plate positioned to return the liquid to its specific tank. This is followed by the starting of the next pump and so the operation is repeated twice more. On completion of all these operations, a signal light is switched on automatically to indicate to the operator that the treatment of the work is finished and that it can now be removed from the spray chamber. Two or three thermometers, each with a range of 0-120 deg. C., are fitted to the machine to check and control the temperatures of both the treatment solution and the hot water for the rinse. Three sizes of the machine are manufactured, which can be supplied for heating by steam, hot water, electricity or gas.

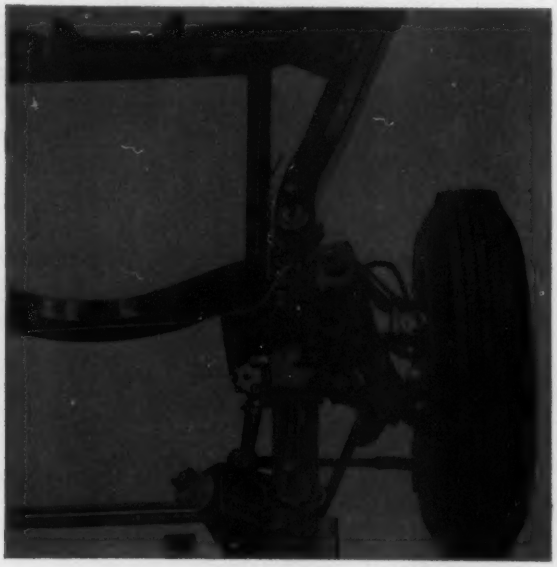


Damping Tripled with Laminated Torsion-bar Springs

A RECENT development by Geo. Salter & Co. Ltd. is the laminated torsion bar. The illustrations show installations (*below*) in the Allard Palm Beach Mk.2 and (*right*) in the new three-litre Rover saloon.

The manufacturers of these springs point out that far greater flexibility can be achieved with a thin leaf than with a thicker one of the same width, and that extra strength can be built up with extra laminæ. This makes possible a torsion bar short enough to be mounted across the open end of a conventional wish-bone, anchoring to the chassis in the middle, where buttressing is largely provided by the front X-member and engine mounting. A considerable advantage at the experimental stage, when different types of bodywork are being considered, is that the springing characteristics can be readily varied to suit by adding or removing leaves. With the long torsion bar, end fixing can involve the costly machining of splines. With the rectangular section provided by a pack of laminæ, anchorage is comparatively simple and inexpensive.

The manufacturers state that the damping capacity of laminated torsion bars is at least 300 per cent above that of the normal torsion bar or coil spring.

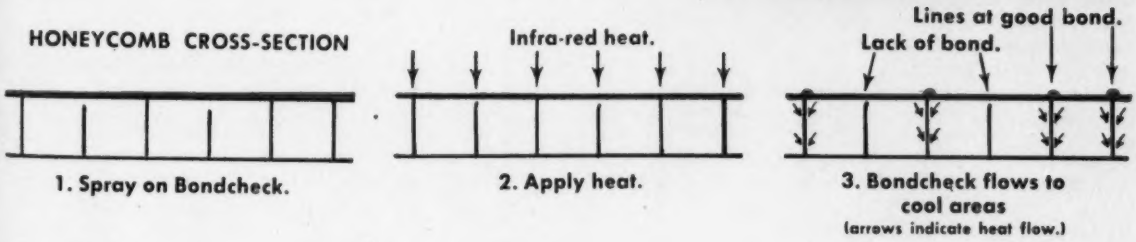


Honeycomb Bond Inspection Equipment Uses New Principle

THE Magnaflux Bondcheck can be used to check the bond in honeycomb structures in metal where the skin surfaces have been soldered, welded or brazed. The principle of operation depends on the use of a special red fluid that is repelled by heat and tends to flow to the coolest area of a metal surface.

The surface to be tested is first cleaned and is then sprayed with the liquid. Controlled heat is then applied from a high-intensity infra-red lamp. This heat is conducted from the surface being inspected to the honeycomb core wherever a good bond exists between the core and the surface. As the liquid flows to the coolest areas, it accumulates at every good bond and produces an exact pattern on the surface. Areas of defective bond are visible as gaps in this pattern. The manufacturers claim that deformed core materials are readily apparent, the inner core pattern being visible in the outer surface pattern. The test only takes a few seconds and complex shapes can be tested.

The inspection kit consists of two separate carrying cases. The first of these contains an inspection stand, spray gun, air hose and pressure-regulating valve, air gauge and filter, Bondcheck fluid and two cans of cleaner fluid. The second case contains a powerstat which enables the inspector to vary the heat intensity of the lamp.



1. Spray on Bondcheck.

2. Apply heat.

3. Bondcheck flows to cool areas (arrows indicate heat flow.)

High-duty hair-pin valve springs (of the type shown above) are used in the B.R.M. racing car. Note also the rocker return springs in the engine. *Photo right: "The Motor"*

DESIGN AND SPECIFICATION OF SPRINGS

Knowledge of the principles and materials used in spring design are essential if the engineering designer is to specify requirements correctly. The main guiding factors involved are examined here

by J. A. ROBERTS, M.Inst.B.E.*

SPRING action in one form or another has been with us for a very long time, but it is a very far cry from the flexed tree bough to the complexity of modern spring engineering. The purpose of a spring is to store energy, cushion recoil, prevent jar and vibration and to give ease and comfort in thousands of ways.

The choice of a material for a spring to meet a given set of conditions is governed by several considerations, i.e., environment, the class of duty to which the spring is subject, and its life requirement. These may vary in their order of importance.

ENVIRONMENT—Under this heading fall in the majority of cases the final governing factors in the selection of a suitable material. The subject may again be subdivided into the following conditions, any one or more of which may apply to any particular spring under consideration: elevated temperature, sub-zero temperature and corrosive conditions (which may include electrolytic action due to the proximity of other parts of dissimilar metals).

On occasion special characteristics are desirable. These may include non-magnetic qualities, high or low electrical or thermal conductivity or a zero thermo-elastic coefficient for very sensitive instrument work. Materials covering all these qualities are now generally available.

CLASS OF DUTY—In general, springs fall into three classes under this heading. They are:

High Duty: Covering springs subject to rapidly reciprocating motion (i.e., I.C. engine valve springs), dynamically or shock-loaded springs.

General Duty: Where the spring is called upon to work infrequently or for limited periods, under slowly applied loads.

Static Load: Where the spring is fitted under a load at a static length and remains so throughout its life.

LIFE REQUIREMENT—Usually expressed in the number of reversals or working strokes before failure or replacement and generally restricted to high-duty springs.

Material Specifications

The specifications in Table 1 cover a range of widely used materials for the manufacture of springs and are subdivided into types.

In addition to these, which are published expressly as spring materials, many other materials are widely used in their manufacture. Among them are phosphor bronze, beryllium copper and brass in strip, sheet and wire form, a range of nickel alloys, including Inconel, Nimonic, "K" Monel, Monel and Ni-span-C and the more newly-developed titanium and cobalt alloys.

Some doubt may exist in the exact choice of specification of material where two or more specifications would appear to be the same. For instance, a valve spring for severe operating conditions requiring a high-duty hard-drawn and ground wire may be considered in EN.49.D, DTD.5a or STA.1, all of which fall into the required category; only a close study of the specification and inspection clauses will make the difference apparent and, after this, economics may enter the field to influence the final choice. Taking this example further, the differences of these materials may be examined.

DTD.5a specification states that:

(a) the blooms or billets used in the manufacture of the rods from which the wires are made shall be turned or ground all over; and

(b) the rods from which the wires are made shall be ground all over at some stage during the manufacture of the wire.

The specification lists a pickling test, tensile and reverse bend test and further lays down that a test piece must be

* *Technical manager, Herbert Terry & Sons Ltd.*

examined microscopically and that freedom from decarburisation shall be to the satisfaction of the inspector.

However, EN.49.D specification states that the blooms or billets should be machined or ground all over and that the wire shall be ground all over, in order to remove all decarburisation and surface defects, preferably subsequent to the final patenting heat treatment. This specification lists tensile, torsion, reverse bend, wrapping, dead wire, deep etch and decarburisation tests where it states that a cross-section prepared and examined as specified shall be entirely free from decarburisation.

The Services specification STA.1 specifies that surface defects shall be removed at various stages of manufacture, as follows:

(a) The blooms or billets from which the rods are rolled shall be machined or ground all over to remove all surface defects followed by pickling and, if necessary, dressed and re-pickled until any remaining defects are eliminated.

(b) The rods shall be ground all over before drawing to remove completely all surface defects. Alternatively, they shall be ground after drawing to a convenient size; this size must be as close as practicable to the original rod size.

(c) The drawn wire shall be ground all over subsequently to the last patenting operation. The wire must then be entirely free from decarburisation and surface defects. The specification lists tests for deep etch, decarburisation, tensile, torsion, wrapping and dead wire.

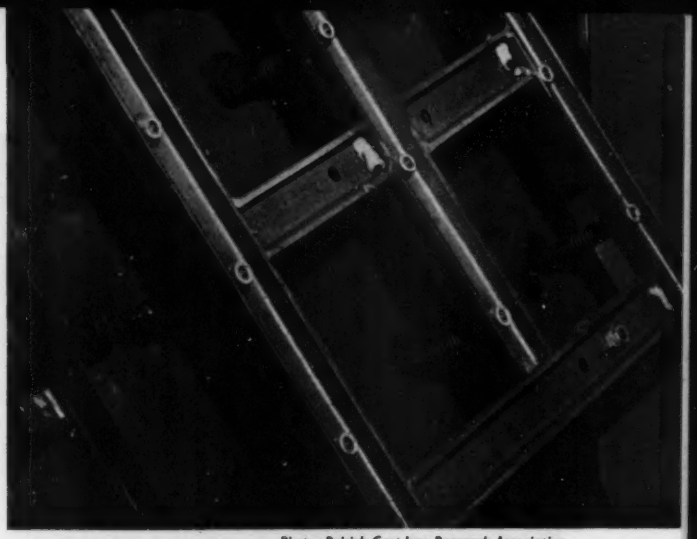


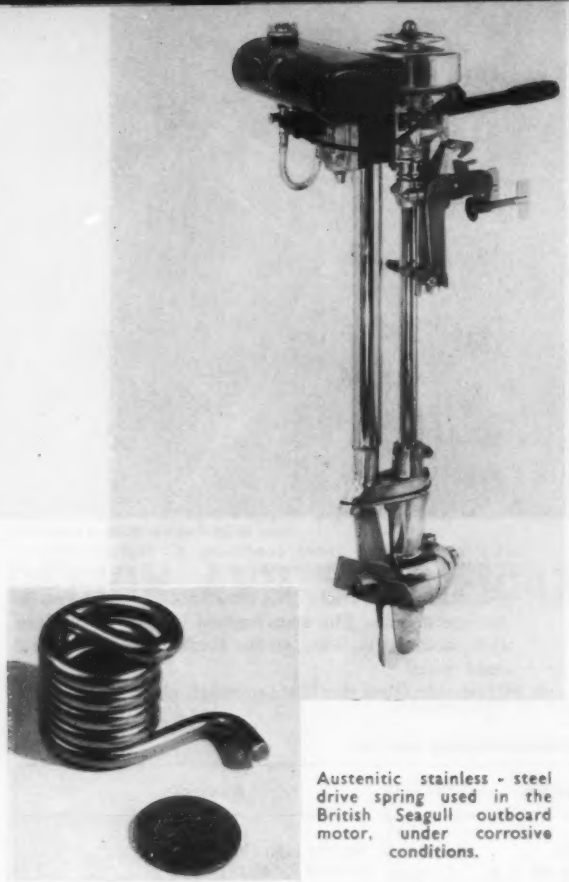
Photo: British Cast Iron Research Association

Ejector springs used under conditions of heat in shell moulding boxes.

It will be seen from this that, although all specify a high-

TABLE I. Specifications for commonly-used spring materials

Spec. No.	Description	Remarks
HARD-DRAWN SPRING STEEL		
BS.1408, EN.49.B	Hard drawn (patented)	Not for high duty
BS.1408, EN.49.C	High-duty wire (not ground)	Suitable for all high duty
BS.1408, EN.49.D	High-duty wire (ground)	Suitable for all high duty
DTD.5A	Hard-drawn carbon steel for valve springs	Ground during manufacture
DTD.215	High-tensile steel wire	Not suitable for high duty
STA.1	Special first-quality hard drawn	Intended for special services applications only
STA.3	High-quality hard drawn	General high-duty wire
STA.4	Standard quality hard drawn	Not for high duty
STA.5 (V22)	Hard-drawn steel for valve springs	Corresponds to DTD.5A
OIL-HARDENING SPRING STEELS		
BS.1429, EN.42.B	Plain carbon steel	0·60/0·70% carbon content
BS.1429, EN.42.C	Plain carbon steel	0·70/0·80% carbon content
BS.1429, EN.42.D	Plain carbon steel	0·80/0·90% carbon content
BS.1429, EN.44.B	Plain high carbon steel	0·90/1·0% carbon content
BS.1429, EN.44.C	Plain high carbon steel	1·0/1·2% carbon content
BS.1429, EN.45	Silicon manganese steel	For highly stressed springs
BS.1429, EN.45A	Silicon manganese steel	
BS.1429, EN.47	Chromium vanadium steel	
BS.1429, EN.50	Chromium vanadium steel	
DTD.4A	Chromium vanadium steel	For highly stressed high-duty springs
DTD.178A	Spring steel strip	
DTD.239A	Plain carbon steel	Not suitable for valve springs
STA.2A	Plain carbon steel	For general duty
STA.2B	Silicon manganese steel	For highly stressed springs
STA.2C	Chromium vanadium steel	
STA.2D	Silicon chromium steel	
STA.5, V22A	Plain carbon steel	For general duty
OIL-TEMPERED STEELS		
BS.2803, Grade 1	Oil-tempered carbon steel	High duty (ground)
BS.2803, Grade 2	Oil-tempered carbon steel	High duty
BS.2803, Grade 3	Oil-tempered carbon steel	Commercial quality
NON-CORRODIBLE STEELS		
BS.2506		
EN.56.A, B, C, and D	Martensitic chromium steel	Selection governed by tensile requirements
EN.57	Martensitic chromium steel	High tensile
EN.58.A	Austenitic chromium nickel rust-, acid- and heat-resisting steel wire	18/8 chrome nickel
EN.58.B		18/8 chrome nickel titanium
EN.58.C		20/10 chrome nickel titanium
EN.58.D		12/12 chrome nickel
EN.58.E		20/10 chrome nickel
EN.58.F.		18/8 chrome nickel-niobium
EN.58.G.		20/10 chrome nickel niobium
EN.58.H.		18/8 chrome nickel molybdenum
EN.58.J		18/8 chrome nickel molybdenum
DTD.326A	12% chromium steel wire	Martensitic *not* suitable for valve springs



Austenitic stainless - steel drive spring used in the British Seagull outboard motor, under corrosive conditions.

duty ground wire, from the wire manufacturer's point of view there is a very considerable difference between each of these materials.

The influence of permissible stress on the choice of material may vary considerably with the exact working conditions, and any generalisation would be not only difficult to lay down but would lead to misunderstandings, due to exceptions to the general rule and to the apparent anomalies under certain conditions. An illustration of this is in the consideration of helical valve springs for I.C. engines where often it is necessary to stress a spring to its absolute limit in order to achieve a natural frequency of the spring sufficiently high to eliminate the risk of breakage due to surge, which can be a source of trouble on lowly-stressed (low-frequency) springs.

Table 2, listing types of material, their primary applications and maximum permissible stress (calculated when compressed to solid in the case of compression springs and including correction of curvature), may be found useful as a guide. However, in all cases of severe stressing, arduous duty or unusual environment, consultation with the spring manufacturer is strongly advised.

Design Formulae

The rate per inch deflection of a compression or extension spring can be obtained from:

$$\frac{Gd^4}{8\,ND^3} \text{ lb./in. deflection.}$$

where G = modulus of rigidity (this varies for different materials and these values are given below);
d = diameter of wire;
N = number of active coils; and
D = mean diameter of coil.

The load-deflection chacteristics of a compression spring with constant pitch is linear, and extension springs follow the same law, except in certain cases where initial tension is coiled into the spring. This initial tension gives a variable load to the spring before the coils begin to open. When this initial tension is overcome, the spring will then follow linear law in its load-deflection characteristics.

The amount of initial tension varies according to the index (D/d). The smaller the index, the greater the amount of initial tension.

The stress can be calculated by:

$$\text{Stress} = \frac{8\,WDK}{\pi d^3}$$

where W = load on spring (lb.);
D = mean coil diameter;
d = diameter of wire; and
K = correction factor for curvature.

$$K = \frac{4C-1}{4C-4} + \frac{0{\cdot}615}{C} \quad (C=D/d)$$

For convenience, the values for K against index C is given in Fig. 2.

By incorporating the rate and the stress formulæ one can calculate the stress directly from spring dimensions by:

$$\text{Stress} = \frac{Gd\delta K}{\pi ND^2} \text{ p.s.i.}$$

where δ = deflection.

TABLE 2—Maximum permissible stress of principal spring materials

Class of Material	Special Features	Maximum Permissible Stress
Hard-drawn steel wire	All springs, grade according to duty.	40% of U.T.S. (rising to 50% on wire below 0·024 in. dia. approx.).
Oil hardening and oil tempered Plain carbon	All springs, grade according to duty.	40% of U.T.S.
Chromium vanadium	Highly-stressed springs	50% of U.T.S.
Silicon manganese	Highly-stressed springs	55% of U.T.S.
Silicon chromium	Highly-stressed springs	60% of U.T.S.
Martensitic s.s.	High corrosion resistance	40% of U.T.S.
Austenitic stainless steel	High corrosion resistance, excellent stability and heat resistance. Properties up to 375 deg. C.	40% of U.T.S. at room temp. dropping to 30% at 365 deg. C.
Phosphor bronze	Non-ferrous.	35% U.T.S.
Hard brass	Non-ferrous.	30% U.T.S.
Beryllium copper	Age-hardening alloy. High mechanical strength, good conductivity and heat resistant to 200 deg. C.	25% U.T.S. (dependent upon precise working conditions)
Inconel	High strength, non-magnetic, nickel-chrome-iron alloy. Corrosion resistant—good at elevated temperatures to 370 deg. C.	35% U.T.S. at room temp. Lower according to temp.
"K" Monel	Age-hardening alloy, non-magnetic. Excellent at sub-zero to −100 deg. C.	30% U.T.S.
Monel	Excellent resistance to corrosion by alkalis and many acids.	30% U.T.S.
Nimonic 90	Heat-resisting, age-hardening alloy for extreme temperatures.	40% U.T.S. at room temperature falling to 20% U.T.S. at 500-600 deg. C.
Ni-span C	Age-hardening alloy. High elastic and mechanical strength properties with a zero thermo-elastic limit.	35% U.T.S.

TABLE 3. Modulus of rigidity values for various materials

Material	Modulus of Rigidity (G)
Steel	11·5 × 10⁶
18/8 stainless	9·15 × 10⁶
Brass (70/30)	5·5 × 10⁶
Phosphor bronze	6·25 × 10⁶
Monel	9·5 × 10⁶
Inconel	11·0 × 10⁶
Ni-Span C	10 × 10⁶
Beryllium copper	6 × 10⁶) Depends on 7 × 10⁶) heat treatment.

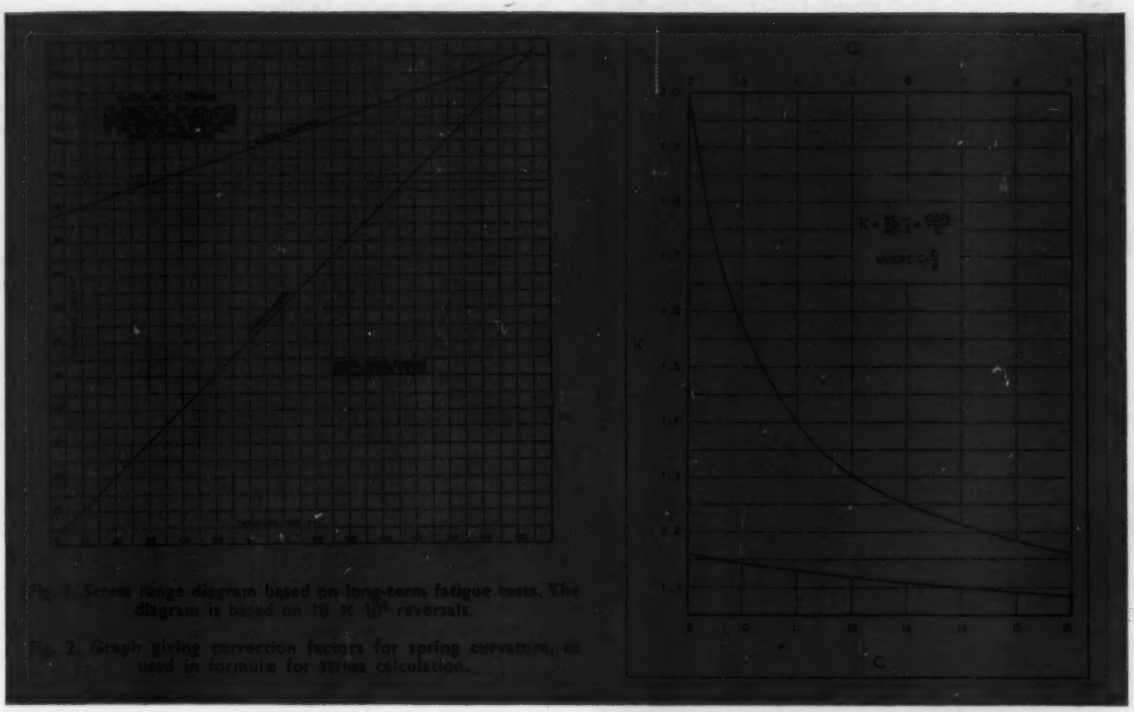


Fig. 1. Stress range diagram based on long-term fatigue tests. The diagram is based on 10 × 10^5 reversals.

Fig. 2. Graph giving correction factors for spring curvature, as used in formulæ for stress calculation.

In designing springs, the maximum stress should not exceed the figures given for maximum permissible stress given in the tables and this maximum stress must be taken when the spring is compressed coil to coil to ensure that the spring is a purely elastic body. The solid height of the spring can be obtained by (N + 2)d. This is for springs with the ends closed and ground. The reader is recommended to consult B.S.1726: "Guide to the Specifying of Helical Compression Springs". This document is a very useful one and does give tolerances, both dimensional and loading, that one can expect from a production standpoint.

In high-duty springs where the number of stress reversals is high, for example, valve springs for I.C. engines, it is vitally important that the stress range is within certain limits, otherwise the life will be short. The stress range diagram given in Fig. 1 has been based on long-term fatigue tests in actual springs and will serve as a reliable indication as to the suitability of any particular design for long life. The diagram is based on 10 × 10^5 reversals.

Another factor to be considered in high-duty springs is the natural frequency of the spring itself. This frequency can be calculated by:

$$\text{Natural frequency} = \frac{844{,}800d}{ND^2} \text{ cycles/min.}$$

One should aim at the highest possible frequency, so that if resonance does occur it does so at a high harmonic order, where the amplitude is at its lowest, thus minimising local high stresses which lead to rapid failure. It will be seen that to obtain a high frequency one must use the highest possible stress the material is capable of, and therefore the information given earlier assumes major importance in the design of any particular spring.

HOLLOW DIE-CASTINGS FROM NEW MACHINE

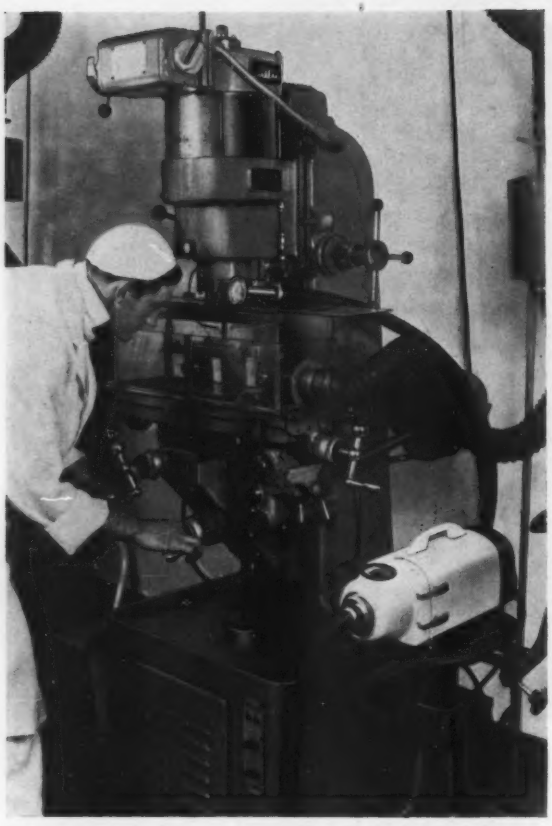
HOLLOW die-castings without the use of a central core in the die may be produced on a machine invented by Mr. J. D. Guest and recently introduced by Robar Products (London) Ltd.

Such articles are produced by injecting the metal into the die cavity, allowing the metal immediately in contact with the die to form a "shell", and then evacuating the metal in the centre of the article while still in the molten state. The thickness of the shell can be controlled down to 0·020 in. with a tolerance of ±0·005 in. There is no limit to the size of the hollow article; in fact, it is claimed that the larger the article the simpler it is to evacuate the central molten metal.

The machine can be semi- or fully-automatic. The evacuation of the centre metal while in its molten state is achieved by a number of closely-controlled operations. The complete cycle is controlled by a special timing mechanism, which is infinitely adjustable.

The machine can operate at all the normal temperatures for pressure die-casting, but it is usually found advantageous to run the die cooler (about 80 deg. C.) than is normal. This results in a number of advantages: (1) the complete operation cycle, being from 3-10 sec. even for large articles, means increased production within a given time; (2) the short "dwell" period reduces the corrosive effect of the metal on the die which therefore need not be of such high-quality steel as is normally used; (3) as the die is run below the critical tempering temperatures for steel, it remains harder and thus has a longer life, and flash on the article is reduced; and (4) the speed of the injection is such that the metal is forced into the die with little loss of heat, and also, as the temperature of the die is precisely controlled, the surface of the casting is of a particularly dense structure highly suitable for plating.

Solid castings, which may, of course, also be produced from the machine, are made in the usual way.



In the course of milling beryllium, samples of air breathed by the operator at Metropolitan-Vickers are taken and measured by the instrument shown bottom right of picture. Most particles are removed by means of main extractor.

GROWING USES FOR BERYLLIUM

Although interest has been focused on the uses of beryllium in nuclear energy, the metal also provides a number of other engineering possibilities. This article surveys some of the special problems involved

by T. H. H. SKEET, L.L.B.

BERYLLIUM is steadily growing in importance commercially as companies in the principal industrial centres of the world are taking an increased interest in its recovery and fabrication.

Production of the metal is achieved by a series of steps, the first of which culminates in the production of beryllium oxide. Following this, methods have been devised for producing the metal in a comparatively high state of purity. These take the form of either using magnesium to reduce beryllium fluoride or electrolysis to reduce beryllium chloride. Metal obtained from either source may be refined by vacuum distillation, though this is unlikely to be used beyond the research stage. The peculiar propensity of beryllium to react readily and to emit fumes injurious to health obliges both manufacturers and fabricators to adopt special precautions which inevitably add to the cost of the product.

Attempts to produce fully ductile beryllium have so far proved unsuccessful. It should be recognised, however, that extrusions and sheet can be produced with increased ductility in the direction of working. It is thought, however, that the metal's low ductility may be partly attributable to impurities, and every effort is being made to improve the quality of beryllium by vacuum distillation and condensation at carefully-regulated temperatures.

Although methods of fabricating beryllium seem reasonably settled, the expensiveness of the product, coupled with low temperature brittleness which appears at the moment insurmountable, retard its broader employment for industrial purposes. Nevertheless, the attraction of high strength and stiffness to weight ratio particularly at elevated temperatures and the ability to withstand corrosion are such that for specific purposes many consider that these and other essential properties may far outweigh its immediate disadvantages. The metal has certainly much to commend it, and while it imparts precipitation hardening and strength to many metals with which it may be alloyed, its own intrinsic properties are seldom enhanced by the addition of other materials.

For fabricating, the metal manufacturers are compelled to resort to powder metallurgy methods which involve vacuum melting in a beryllia crucible followed by further treatment in an inert atmosphere of argon. Vacuum-cast billets are powdered, pressed into appropriate shapes and later machined to fit requirements. Departure from the commoner methods of fabricating metals is brought about largely as a result of the process yielding a much superior wrought product.

Toxicity and Allergies

The metal, sulphate, chloride, hydroxide and fluoride are all thought to give rise to berylliosis in people who are allergic to beryllium. Brush Beryllium Co.* have, however, discovered that while only about one in a thousand are allergic to the metal and its compounds, it is not practicable to reveal such cases in advance. Accordingly, the most stringent safety arrangements are desirable to safeguard the health of operatives. Many of the difficulties experienced occurred in the fluorescent tube industry which involves the use of beryllium-zinc-manganese silicates and, to a lesser extent, in the processing of beryllium-copper alloys. Skin may also be irritated by contact with soluble beryllium compounds giving rise to

* O.E.E.C. study "Ti and Zirconium and other elements", 1956, p. 94.

dermatitis or ulcers which are likely to persist until the infection is removed. Care should therefore be taken if the metal is machined wet, particularly with cutting fluid, lest it should escape into the machine and later dry out, giving rise to the injurious dust. Appreciating these and allied difficulties, the U.S. Atomic Energy Commission in 1949 determined the extent of injurious concentration and outlined safety measures thought desirable.

In the U.K. there are several companies conducting research into the potentialities of beryllium and/or producing and fabricating the metal. Among these are I.C.I. Ltd. (who are building Europe's first production-scale wrought beryllium plant), the Consolidated Zinc Corp. (who operate a pilot plant for production of beryllium metal for the U.K.A.E.A.), Murex Ltd., Tube Investments Ltd. (concerned with fabrication problems), General Electric Co. Ltd. (studying nuclear applications) and Metropolitan-Vickers Electrical Co. Ltd. (who are investigating the fabrication of the metal into reactor fuel element components).

For the protection of operatives the general provisions of the Factory Act, 1937, and its amendments apply. Section 47 provides *inter alia* that:

> "In every factory in which, in connection with any process carried on, there is given off any dust or fume or other impurity of such a character ... as to be likely to be injurious ... to the person employed ... all practicable measures shall be taken to protect the persons employed against inhalation of the dust or fume ... and to prevent its accumulating ... and, in particular, where the nature of the process makes it practicable, exhaust appliances shall be provided and maintained ..."

The wording is self-explanatory and throws the onus on employers to evolve a satisfactory system for the protection of their workmen. Both Sections 27 and 28 of Part II of the Act are extendable to beryllium facilities. The former requires that precautions shall be taken if workmen are engaged in confined spaces where dangerous fumes are likely to be present, while the latter refers to steps that should be taken in the event of explosive or inflammable dust, gas or vapour being present.

The beryllium industry is virtually in its infancy in the U.K., as commerce generally is only just beginning to appreciate the potential of the metal and its alloys. It is noteworthy, however, that research in this country is being conducted by reputable companies which, being apprised of the risks involved, have taken steps to ensure the safety of their operatives. In these circumstances, the need for special regulations to cover the nascent industry does not appear to have emerged. The Minister of Labour has power, however, to issue them under Section 60 of the Act should the need arise at a later date.

The general provisions of the Act will continue to apply until the need arises for formulating a more specific code covering beryllium plants. It is instructive to observe in passing the approach of I.C.I. Ltd. to this problem: "Thanks to considerable research which has been carried out into the safe handling of beryllium products by the U.K.A.E.A., stringent standards of operation have been evolved and codified, and the I.C.I plant—which will come into operation towards the end of 1959—will incorporate all the special features which have been found necessary for this purpose." Doubtless other companies have taken advantage of the experience of others and have begun measures calculated to minimise the risks involved. Thus, apprised of the toxicity of beryllium and supported by acceptable precautionary measures, manufacturers may handle the material as safely as any other metal.

U.S. Production

The leading beryllium producers in the U.S.A. are the Beryllium Corp. of Reading, Penn., and the Brush Beryllium Co. of Cleveland, Ohio. Until recently, the only complete beryllium fabricating plant there belonged to the U.S.A.E.C., and until the end of 1955 the sole source of nuclear-grade beryllium was a government-owned plant operated by Brush. Following a series of policy changes, private industry was invited to participate and to take over the supply of the metal from the Government

Dimensional checking of a beryllium assembly fabricated from hot-rolled sheet and Brush QMV block.

Right. Cutting large section of Brush QMV beryllium block for further machining.

TABLE 1. Uses and characteristic properties of beryllium

Product	Use	Special Properties
Beryllium metal	*Nuclear*: Moderator, reflectors, canning material for fuel elements, neutron source, tubes, etc. X-ray tube windows. *Aircraft*: Structural parts or components, including wing surfaces, skins, air intake, tubes of jet aircraft, exhaust outlets, brake components and instrumentation. *Missiles*: Nose cones and components.	Low-neutron capture cross-section and ability to moderate the velocity of neutrons in reactors. Permeability by X-rays and high melting point. 1. QMV warm extruded beryllium is four to five times stronger than 316 stainless steel on a tensile-strength-to-density basis. 2. QMV warm extruded beryllium has over 50% higher modulus of elasticity than 316 stainless. 3. About 70% of the weight of Al. 4. Melting point of beryllium (1,280°C.) compares with 660°C. for Al. 5. Maintains its essential properties at about 540°C. and in alloy from even higher temperatures.
Beryllium oxide	High-temperature refractory material. Probable nuclear applications include use as a moderator and/or reflector in reactor systems.	Crucibles manufactured from the oxide are resistant to thermal shock, maintain high rate of heat conductivity and do not contaminate the melt. Melting point of oxide about twice that of berryllium, Good thermal conductivity and insulating properties for h.f. current.
Beryllium-copper alloys	Wide range of springs for electrical appliances; for aircraft fuel gauge instruments; non-magnetic springs for transmitters and gyros; dynamo brush springs; selected springs for military equipment. Switches, switchgear, electrode holders, etc. Bearings, sleeves, bushings and gears. Watches, instruments, electronic appliances, tools and equipment.	Six times as strong as pure copper, beryllium imparts precipitation hardening to the alloy and greater tensile strength. High electrical and thermal conductivity. Resistance to wear, corrosion and fatigue. Non-magnetic and non-sparking.
Beryllium-aluminium alloys	Limited commercial use.	Addition of beryllium to aluminium is an advantage in casting Al alloys. Addition of beryllium to Al-Mg alloys prevents loss of magnesium through oxidation during melting and inhibits discoloration during heat treatment.
Beryllium-nickel alloys	Surgical instruments and needles, precision springs, components of aircraft fuel pumps and matrix in diamond drill bits.	Maintain essential properties at high temperatures and are comparable with stainless steel in strength, hardness and ability to withstand corrosion.
Beryllium-iron alloys	Miscellaneous industrial applications. Particularly watch springs. Particularly for surgical instruments requiring significant strength and resistance to corrosion.	Various alloys are available including: Beryllium 1%, chromium 12%, nickel 11% for strength and hardness at elevated temperatures. Beryllium 0·5%, nickel 30%, tungsten 8%. Beryllium 0·6%, nickel 60%, chromium 15%, molybdenum 7%.
Beryllium silicates	Affords a lining in fluorescent lighting tubes in certain countries and application in T.V. screens	
Beryllium nitrate	Incandescent gas mantles.	Strengthens the oxide skeleton of the mantle.
Beryl	Substitute for felspar in manufacture of porcelain, especially when electrical properties are required, i.e., for sparking plugs.	High electrical resistance and low thermal expansion.

agency. Accordingly, two contracts were awarded by the U.S.A.E.C. to both the Beryllium Corp. and Brush valued at $23 million each and covered together the delivery of 500 Sh.T. of nuclear-grade beryllium metal over a five-year period starting in 1958.

It will be appreciated that advances in nuclear technology have opened up new and promising markets for beryllium, and this may be gauged from the fact, quite apart from the scope of recent contracts, that the metal has been employed in nuclear installations which include the U.S.A.E.C. submarine reactor and the engineering test reactor at Idaho Falls. Currently, however, over 80 per cent of all beryllium used in the U.S.A. in commercial applications is employed in alloy form associated primarily with copper.

Copper, nickel, cobalt, palladium and silver are all to some extent soluble in beryllium, but only the first two are commercially significant at the moment. And while beryllium-copper accounts for about 80 per cent of current beryllium output, only a small quantity measuring between two and five per cent is actually used in the alloy which may be worked in a relatively soft state before being brought to its ultimate strength through a heat treatment. The tensile strength of the copper is considerably enhanced and its ability to withstand fatigue is greatly strengthened. Precipitation hardening is imparted to copper. The addition of two per cent beryllium and 0·5 per cent cobalt gives excellent electrical properties; if these figures are transposed in such a way that the percentage of cobalt is greater than that of beryllium, the alloy combines also effective heat and fatigue resistance, making it suitable for electrical springs and switches.

Another interesting characteristic of the alloy is its non-magnetic properties which single it out for use in watches, instruments and electric equipment. Further, where non-sparking qualities are of advantage in industrial plants such as petroleum refineries, chemical and gas units where explosion may prove disastrous, tools may be fabricated from the alloy which significantly reduces the risk of hazard. The alloy thus embraces a remarkable list of properties—great strength, thermal and electrical conductivity, non-magnetic and anti-sparking properties, resistance

to wear, fatigue and corrosion.

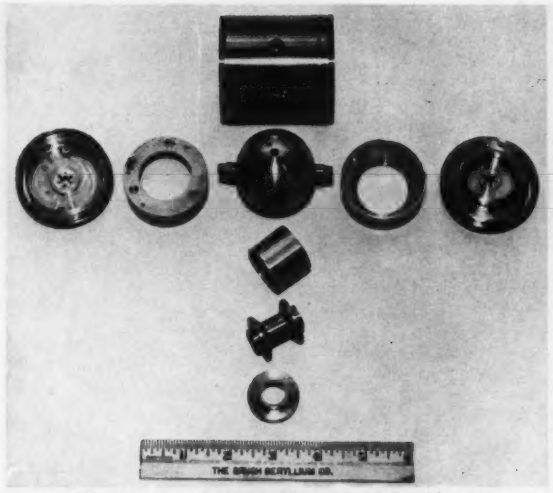
The topicality of beryllium's association with nuclear energy has brought the metal to the forefront of public attention and will doubtless enhance its popularity, quite apart from intensifying research to overcome its manifest weaknesses. The market for beryllium would be much more widespread but for its price, which is at present prohibitive except for special industrial applications. Although the U.S. price has fallen from $100/lb. to the current one of about $47/lb. there seems to be little prospect of it declining appreciably in the near future unless demand is stimulated considerably. The additional drawbacks of poor ductility and brittleness at low temperatures have further militated against a more extensive application.

The stability of the metal under radiation and its ability to reflect neutrons commends it to nuclear manufacturers. While graphite, heavy water and beryllium all qualify as suitable moderators and reflectors for reactors, the last-named is particularly apposite where high temperature, compactness and low weight are material considerations. The power stations now under construction operate at temperatures up to about 470 deg. C. (viz., the temperature to which the fuel cans are exposed inside the reactor) utilising magnesium-alloy canning materials to clad fuel elements. It is evident that higher operating temperatures necessary to obtain increased thermal efficiency will involve the replacement of present canning materials with beryllium in the advanced gas-cooled systems where fuel element surface temperatures may be expected to rise to approximately 600 deg. C.

Tube Investments Ltd. have made some progress solving the problems that affect the fabrication of beryllium for nuclear purposes. Experimentally, a tube 2-3 ft. long with a 0·30-in. bore and wall thickness of 0·04 in. has been drawn in the company's research laboratory. Apparently tubes of a broader diameter and up to 10 ft. in length have also been fabricated.

While the incidence of company research seems to be directed towards improving the performance of beryllium and its alloys for nuclear purposes, sight should not be lost of the possible application of the metal to meet the requirements of high-speed aircraft and guided missiles.

Aircraft research is certainly directed towards developing lightweight structural materials. Aluminium, magnesium and titanium are all potential competitors, and steel still accounts for a large share of aircraft requirements. It will nevertheless be realised that beryllium is three times as strong as steel on a strength/weight ratio and



Precision-machined beryllium inertial guidance components.

maintains its essential properties above 540 deg. C. On the other hand, it is lighter than aluminium and possesses a series of properties which collectively outstrip its rivals. Price and lack of ductility are the principal snags at present. The following figures indicate the comparative melting points of several selected metals:

Beryllium	1,280 deg. C.
Aluminium	660 deg. C.
Magnesium	650 deg. C.
Titanium	1,655 deg. C.

Beryllium combines a high modulus of elasticity with a relatively high melting point, the latter of which may be significantly extended if alloys are employed.

Attempts made to provide an alloy of beryllium and magnesium for structural purposes have succeeded in spite of the fact that the melting point of beryllium is somewhat above the boiling point of magnesium. The Magnox alloys used for canning in gas-cooled reactors comprise these two metals.

Accelerated research for nuclear developments will doubtless improve the prospects of beryllium for other purposes and it would seem clear that aircraft and missile manufacturers would welcome the elimination of the difficulties that at present impede its progress.

FOAMED ALUMINIUM IS ULTRA-LIGHTWEIGHT

ONE of the most interesting developments in the current search for new materials is the production of foamed or cellular aluminium and aluminium alloys. This material, which has been called Foamalum (after the Foamalum Corp. of America, which is responsible for its production), seems to open up immense possibilities.

Using sand, permanent or shell moulds, Foamalum can be cast into fairly intricate shapes with reasonable control in density, which may be varied between 20-70 lb./ft.^{3}, as compared with ingot aluminium which has a density of approximately 160 lb./ft.^{3}. In casting, a skin of solid aluminium is formed at the mould faces with a core of foamed metal in which the cells or bubbles are smaller near the surface of the casting, but the difference in size between these cells diminishes as the density of the casting is increased. An extremely lightweight product can be obtained by removing the outer solid aluminium skin.

The physical properties of components made in Foamalum are almost in proportion to the weight of the foam as compared to the ingot metal; therefore, some measure of tensile and compressive strength may be obtained without recourse to individual tests. The material has good rigidity and a malleability which enables it to be pressed into various shapes without risk of the cells splitting, and since it is non-absorbent it will float on water even when the outer skin is removed. It is interesting to note that as the material is compressed it gains in strength, and preliminary tests indicate that the original ingot strength can be reached when only 50 per cent of its density has been attained.

With the increasing use of sandwich materials in many different industries, Foamalum should readily find a place either as a core material or, by virtue of the outer skin formed in the manufacturing process, as a sandwich material in its own right.

It lends itself readily to bonding by the various types of high-strength adhesives now available and has the advantage that it may be welded by normal techniques.

In addition to its buoyancy, it has a heat loss of one-eightieth of that of solid aluminium which should enable Foamalum to be used with advantage where both thermal-insulation and fire-resistance properties are required.

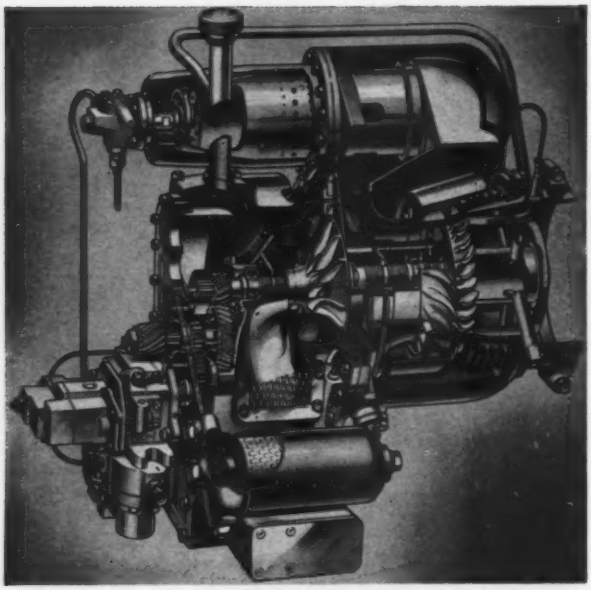


Fig. 1. Cutaway view of the Rover 1S/60 gas turbine engine.

PORTABLE GAS TURBINE UNITS

The small gas turbine, available as a compact and reliable unit at competitive cost, offers to designers a multi-purpose unit suited to many industries where power, heat or air supplies are required

THE aspect of gas turbine development that has become most well known in the public mind is that primarily associated with aircraft propulsion. But the gas turbine is far from being a new development, first patents being granted for it in 1791, nor is it limited in application, for today it is to be found in various forms in every branch of industry and using many types of fuel ranging from paraffin to pulverised coal.

While the correct design of a gas turbine is a matter of science, it is generally accepted that a large turbine is an easier design proposition than a small one, since for a given gas flow the same torque is available at a lower rotational speed. This in turn leads to smaller and less highly-loaded reduction gears, bearing loads, etc. To increase the power output on the smaller sizes, the designer must resort to higher speeds and hotter and faster gas transfers with all their attendant and cumulative difficulties, one of the foremost of which is the correct choice of materials.

It is therefore of considerable interest to find that the gas turbine is finding a new place in the "packaged power" field where long life and reliability are essential. For such typical applications as motor cars, rail vehicles and pumping sets, the reliability of these units stems from the intensive research and investigations carried out in the design stage of their airborne counterparts.

In addition to providing shaft power, the gas turbine is an ideal medium for supplying quantities of air at various temperatures, pressures and mass flows for processing and heating in many industrial plants.

The gas turbine automobile engine, although not yet in large-scale production, has received a good deal of publicity which has tended to overshadow the success of the more prosaic and utilitarian pumping and generating sets that are already in wide use. Before gas turbines can be fully competitive with internal combustion engines and diesel engines for automotive use, manufacturing costs will have to be reduced concurrently with a substantial increase in overall efficiency. The two leading obstacles in the way of these objectives are probably the cost of the turbine wheel and the performance of the heat exchanger.

In this country the turbine car is exemplified by the Rover T.3 which uses an engine based on the 1S/60 unit, the only other manufacturer in this field being the Austin Motor Co., who have installed experimentally a 125-b.h.p. turbine in a Sheerline chassis.

Chart indicating possible uses for the portable gas turbine, both in aircraft and general engineering applications

Aircraft	
Airborne	**Ground**
Helicopters Auxiliary power unit Booster unit Main propulsion	Air starting Ground conditioning Universal ground services
General	
Land	**Marine**
Electrical power Mechanical power Compressor Prime mover	Secondary power Main propulsion Emergency power

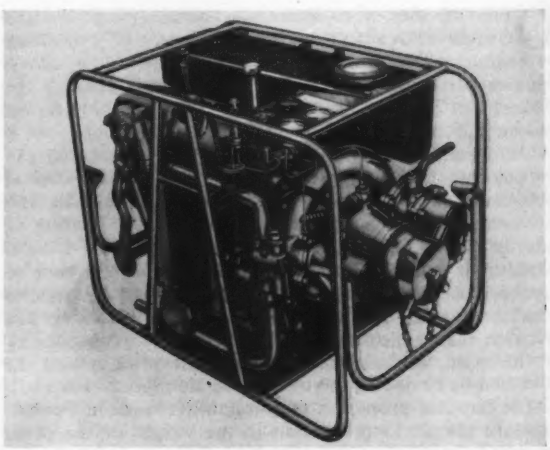
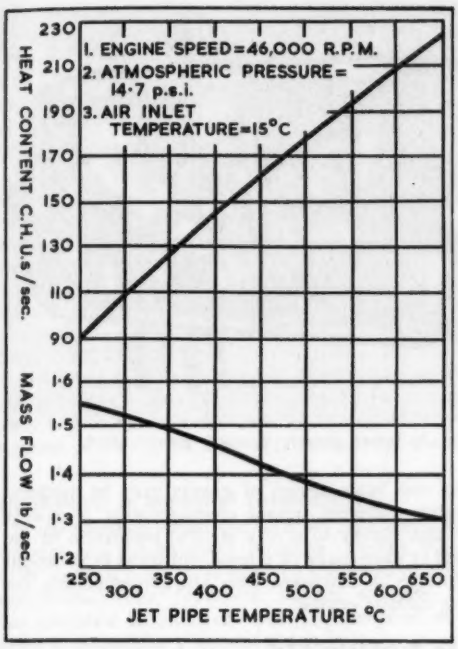


Fig. 2. Rover water pumping set, with a capacity of 500 Imp. gal./min.



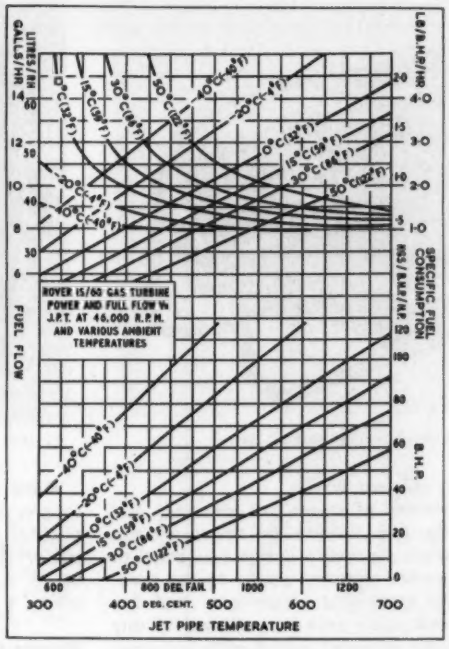

ROVER 15/60 GAS TURBINE POWER AND FULL FLOW Vs J.P.T. AT 46,000 R.P.M. AND VARIOUS AMBIENT TEMPERATURES
FUEL FLOW
SPECIFIC FUEL CONSUMPTION
B.H.P.
JET PIPE TEMPERATURE

Fig. 3. Performance characteristics of the Rover 60-h.p. gas turbine.

With these facts in mind, it is of interest to consider what is possibly the smallest gas turbine engine ever built. Known as the Titan and designed and built in the U.S.A. by Solar Aircraft Co., this unit is only 20 in. high with a maximum diameter of 15½ in. Weighing only 50 lb., the shaft delivers 55 h.p. plus approximately 12 lb. of jet thrust. Although built specifically to power the one-man flying platforms, it is envisaged that its small size and high power/weight ratio will make it equally well suited for land propulsion units and non-airborne applications.

In this survey the gas turbines mentioned have been limited to those which may reasonably be regarded as portable and do not exceed approximately 500 shaft horsepower.

In gas turbines, and particularly those used industrially, variations occur mainly in the conception of the compressor and turbine, and in the arrangement of the combustion chambers. The compressors fall into two groups, the axial compressor and the radial or centrifugal compressor. Due to its long use as an engine-driven blower for supercharging, the radial compressor has received many years of intensive development, so that its performance and reliability are well established. While the diameter of such a compressor is necessarily greater than that of an axial type, it is cheaper to produce, is more robust, can be run at higher speeds and has a wider effective operational range; in this respect it is more suitable for variable speed and load duties. In the axial compressor, a large number of stages are employed, and the pressure is raised at each stage, the rate of acceleration at each stage

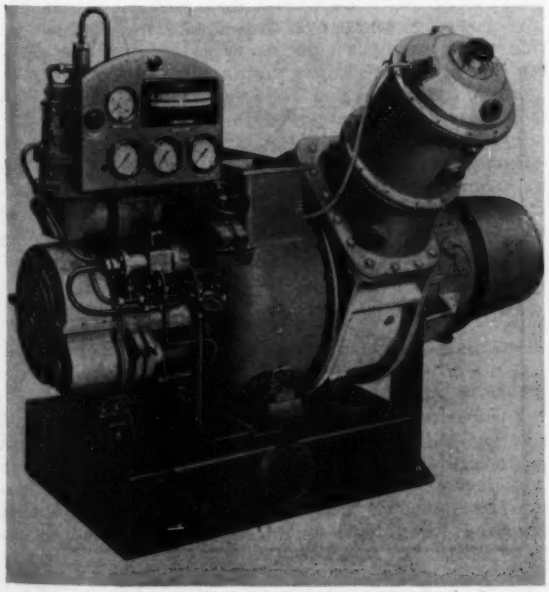


Fig. 4. Ruston & Hornsby TE 300-kW. gas turbine.

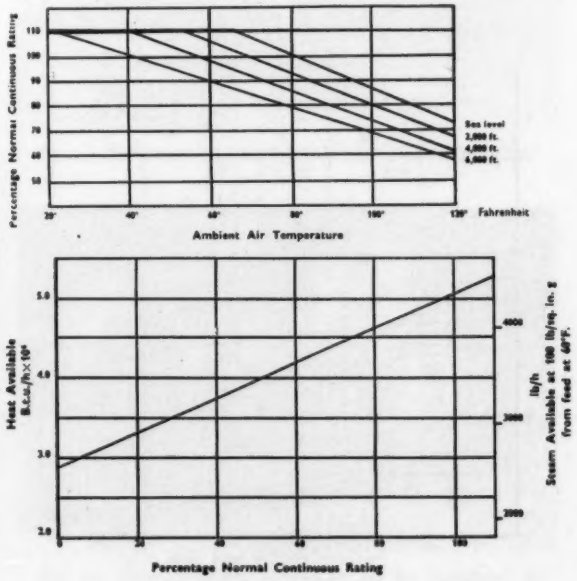


Fig. 5. Performance curves for the TE 300 kW.

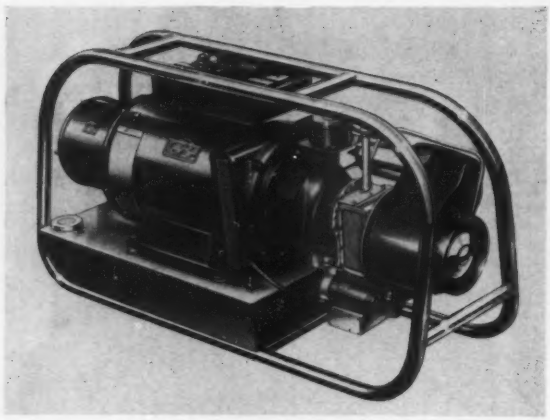


Fig. 6. Petbow/Rover generator set.

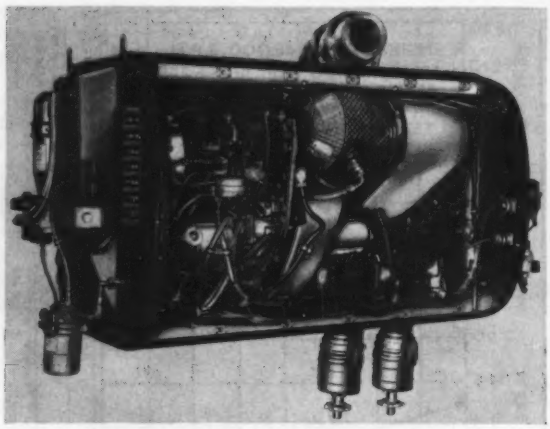


Fig. 9. Rover aircraft auxiliary power plant.

being maintained at an efficient level.

In the turbine, the number of stages can also vary and in what is known as the free turbine the stages are not necessarily directly coupled. In such a design it is usual to find one or more stages are coupled direct to the compressor drive while the remaining stages are used for power take-off. The combustion area may consist of one or more combustion cans arranged peripherally adjacent to the turbine, or one common can, often known as a cannular system. All these variations are employed to produce the most efficient design suited to the engine's particular purpose.

Since any one basic design of engine may be modified to give slightly different output characteristics, it is only possible in this survey to give a general indication of the performance of each make of engine, but these facts should be of assistance to designers who are contemplating the use of a gas turbine engine.

Rover Gas Turbines Ltd.

The Rover industrial gas turbine, weighing 174 lb., is a single-shaft engine having a continuous output rating of 60 b.h.p. at normal temperatures and pressures, and will operate on all distillate fuels, such as kerosene, and natural

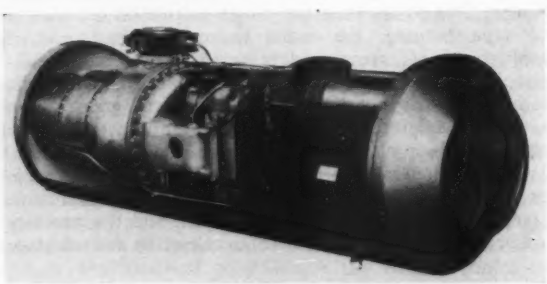


Fig. 7. Artouste 510 series gas turbine.

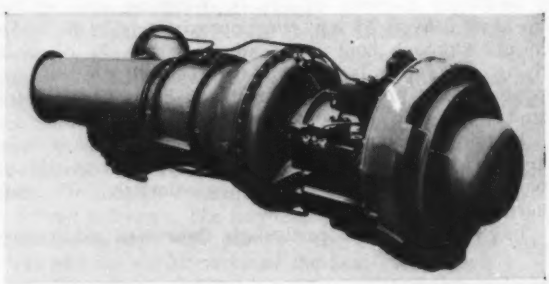


Fig. 10. Blackburn & General A129 engine.

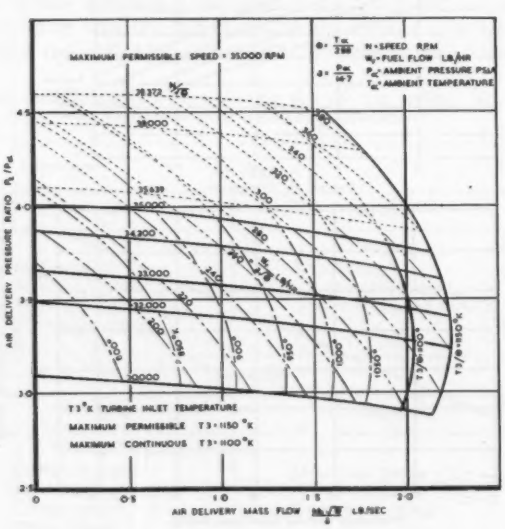

MAXIMUM PERMISSIBLE SPEED = 35,000 RPM
N = SPEED RPM
W_f = FUEL FLOW LB/HR
P_{as} = AMBIENT PRESSURE PSIA
T_{as} = AMBIENT TEMPERATURE
AIR DELIVERY PRESSURE RATIO P_2/P_{as}
AIR DELIVERY MASS FLOW LB/SEC
T3°K TURBINE INLET TEMPERATURE
MAXIMUM PERMISSIBLE T3 = 1150 °K
MAXIMUM CONTINUOUS T3 = 1100 °K

Fig. 8. Performance characteristics of the Artouste 510.

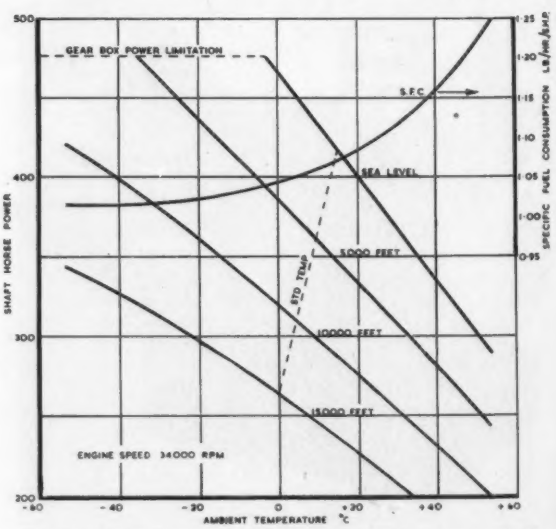


Fig. 11. Performance characteristics of the Artouste 600 series engine.

gases such as methane. Shaft output speeds from 3,000 to 14,000 r.p.m. can be arranged to suit specific applications. The fuel consumption using liquid fuels is 1·4 lb./b.h.p./hr. The general characteristics of the engine are illustrated by the curves in Fig. 3. Typical applications for it are electrical power production, compressor drives, pumping and general auxiliary services.

The single-stage centrifugal-type compressor is driven by a single-stage axial turbine wheel mounted on a common shaft. A single combustion can is used, the fuel system incorporating a multi-piston pump with automatic control for maximum speed and temperature.

The 1S/60 gas turbine unit is also available either as a self-contained pumping unit or as an airborne auxiliary power plant. The complete pumping set weighs 225 lb. and delivers 500 gal./min. with a 10-ft. static lift at a pressure of 100 p.s.i. The airborne unit gives electrical power (32 kW. at sea level) and an air bleed of 0·7 lb./sec. at 44 p.s.i. absolute in ambient conditions of 15 deg. C. and absolute pressure of 14·7 p.s.i. The approximate weight is 400 lb.

Blackburn & General Aircraft Co.

In the range of small gas turbines manufactured by this company are the Palouste, Artouste, Turmo, Plas and the A129, and each of these may be modified to suit specific applications. The following figures indicate the chief characteristics of each type with the exception of the Plas, which is essentially a jet-propulsion unit.

PALOUSTE 500 SERIES—This is an air-bleed gas turbine embodying a single-stage centrifugal compressor. Bleed air is obtained by using a compressor with a greater mass flow than the turbine, the excess air being available at a delivery flange on the casing. Uses to which this engine may be put include aero-engine starting, via an air turbine, and for supplying motive power for rotating wing aircraft through wing-tip jets.

Engine	*Air Delivery* (*lb./sec.*)	*Pressure* (*p.s.i.g.*)
Palouste 502	2·2 max.	38·5
Palouste 505	2·7 max.	41
	2·6 continuous	38

HIGH-PRESSURE PALOUSTE—Derived from the standard Palouste, the high-pressure version is achieved by the embodiment of a second-stage compressor. Primarily intended for main engine starting where high pressures are required, it can also be used as an airborne auxiliary power unit or as a ground servicing power plant. The air delivery rate is 2·0 lb./sec. at a pressure of 70 p.s.i.g., maximum rating.

ARTOUSTE 510 SERIES—This engine provides both shaft power and compressed air, and is potentially an airborne unit from which both motive power and bleed air can be obtained. While many variations in performance are possible with different proportions of air bleed and shaft power, the following values are typical:

Air Delivery (*lb./sec.*)	*Pressure* (*p.s.i.g.*)	*Shaft Power* (*b.h.p.*)
2·4 max.	37·5 max.	0
1·9 continuous	40·4 continuous	100 continuous

ARTOUSTE 600 SERIES—The 600 series engines provide a higher shaft horsepower output than the 510 series, but have no provision for air bleeding. The characteristics of these engines render them very suitable for industrial applications, particularly for electrical power generation. Helical gears give the required speed reduction, and the engine has a typical maximum continuous rating of 410 b.h.p.

TURMO 600 SERIES—The Turmo is a free-turbine shaft drive engine, possessing great flexibility and immense low-speed torque. Its light weight and variable-speed shock-free drive render it suitable for a wide range of applications.

Engine	*Shaft Power* (*b.h.p.*)
Turmo 601	400 max. for 5 min
	350 max. continuous
Turmo 602	325 continuous
Turmo 603	366 max continuous

A 129 ENGINE—This engine is also a free-turbine shaft

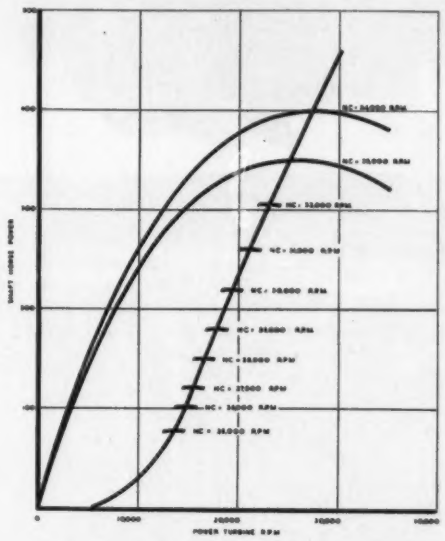


Fig. 12. Performance curves for the Turmo 600 engine.

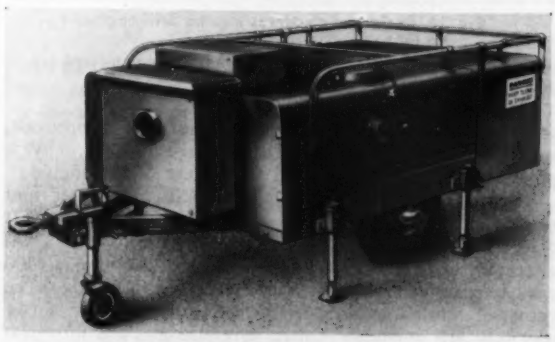


Fig. 13. Blackburn Mk.4 SE air-starter and electrical power trolley

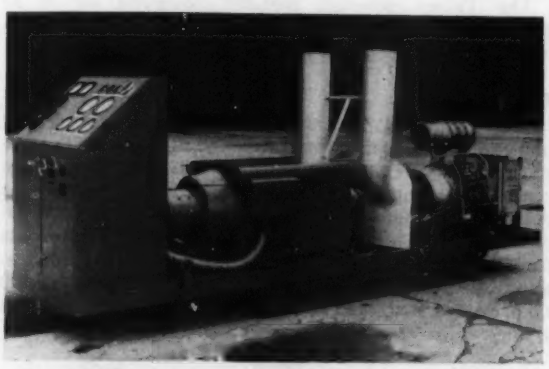


Fig. 14. Turmo-powered alternator set by Blackburn & General Aircraft Ltd.

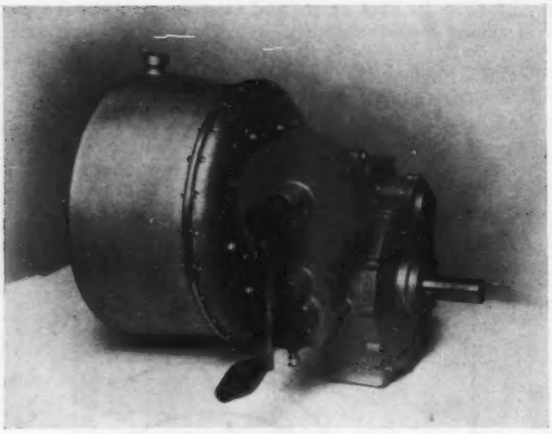


Fig. 15. Brill 45/60-h.p. gas turbine by David Budworth Ltd.

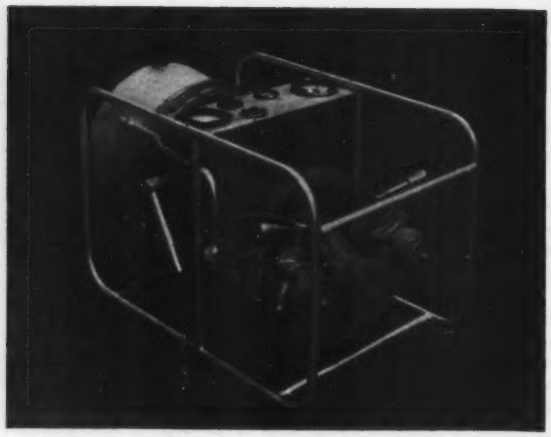


Fig. 17. Budworth-Hayward Tyler pumping set.

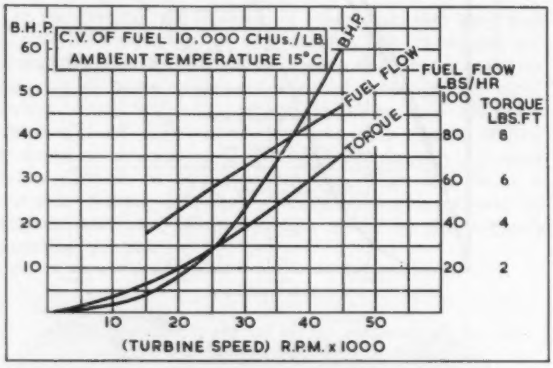


Fig. 16. Performance curves for the Brill engine.

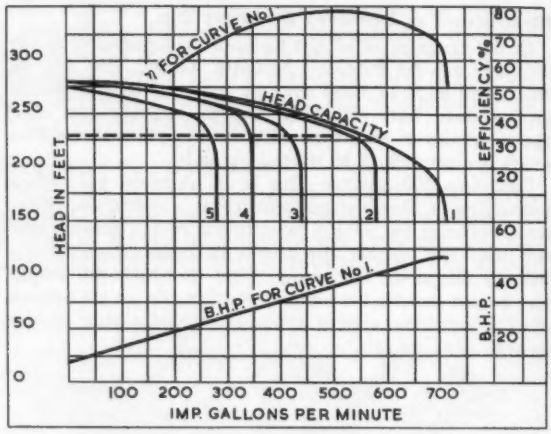


Fig. 18. Pump characteristics of the Budworth-Hayward Tyler unit at 3,600 r.p.m.

drive model embodying a two-stage axial flow compressor, while the third stage of the three-stage turbine delivers power to the gearbox situated at the rear of the engine.

TYPICAL APPLICATIONS—The Mk. 4SE air starter and electrical power trolley uses a Artouste air bleed/shaft drive engine coupled to an English Electric 40-kVA. alternator delivering 208 volts, 11 amps, 3 phase at 400 cps. Alternative equipment for the power take-off can be provided, while a standard range of trolleys for air starter use only are available. Other developments are universal ground servicing vehicles based on the long-wheelbase Land-Rover chassis.

The Turmo powered portable alternator set is an example of a compact, lightweight unit capable of a continuous output of 250 kVA.

Centrax Ltd.

The Centrax C.T.7 industrial gas turbine, at present undergoing development tests, is a 430-s.h.p. unit with three stages of turbine and a seven-stage axial plus single-stage centrifugal compressor directly coupled. A cannular-type combustion system with three burners is employed. Applications for this turbine will include portable generator sets for stand-by use, pumping duties and air-bleed applications. Also under development is the Mk. 2 unit of 500 s.h.p. with a two-stage turbine and a five-stage axial plus a single-stage centrifugal compressor.

David Budworth Ltd.

The Brill 45/60-h.p. lightweight gas turbine consists of an annular combustion chamber surrounding a radial compressor and turbine mounted back to back on the same shaft. Any distillate fuel can be used with the low-pressure fuel system and the consumption using gas oil is approximately 10/12 gal./hr. Among the applications to which this engine is currently put are alternator sets, fire pumping sets, pneumatic conveying and the propulsion of small aircraft and high-speed boats.

Ruston & Hornsby Ltd.

The TE 300-kW. engine has been designed to exploit the inherent simplicity, light weight and small bulk that the gas turbine offers. The impeller for the single-stage centrifugal compressor is manufactured from high-tensile alloy steel, an alternative material being martensitic stainless steel where corrosive conditions are envisaged, i.e., marine applications. The three-stage axial-flow turbine is directly coupled to the compressor and output shaft to the gearbox, which reduces the rotor speed from 19,250 r.p.m. to either 1,200 or 1,500 r.p.m. through helical gears.

The fuel is fed to the burner via twin filters by a gear-type pump, the consumption using a distillate oil being 1·25 lb./b.h.p./hr. at sea level at an ambient temperature of 27 deg. C.

This engine has a normal continuous rating of 430 b.h.p. at 27 deg. C. (80 deg. F.) and is ideally suited for electric power generation, for powering marine craft and for oil-field services. A high thermal efficiency is claimed when the engine is used in conjunction with an exhaust heat-recovery plant for supplying hot air.

OVER 16,000 DEG.C. POSSIBLE WITH PLASMA TORCH

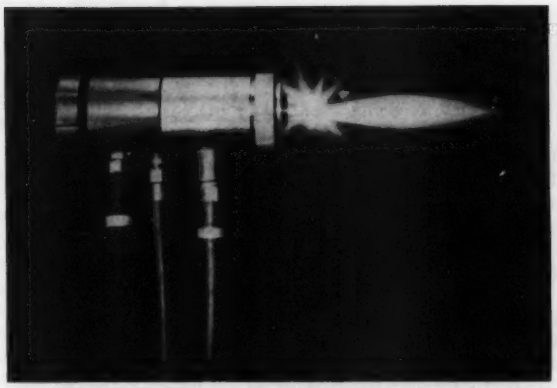
PLASMA is essentially any material heated to an ionised state of high energy. In a number of plasma torches developed in the U.S.A., most of which are capable of attaining a temperature of 16,650 deg. C., the principle of operation consists of blowing a gas through an arc contained within a water-cooled tube. As the gas passes through the arc it is heated to the required temperature, this being attained by regulating the gas flow (from a few feet per sec. to 34,000 f.p.s.) and power output. The flame resembles an oxy-acetylene flame in shape and appearance and special nozzles and extensions may be used to inject solids, liquids and gases into the flame area. In addition to the increased heat which may be obtained in comparison with oxy-acetylene torches, a direct saving in costs may be realised, since inexpensive gases like nitrogen may be used.

From 65-80 per cent of the d.c. generator power is transferred to the torch electrode, and at maximum temperatures the hourly operating cost is nearly one-third of that needed for oxy-acetylene equipment with the attendant advantage of choice of gas.

With a torch capable of reaching and sustaining such high temperatures, research on chemical synthesis, high-temperature materials (such as the carbides), aerodynamic heating, ion, free radical and propulsion studies are likely to be given an impetus.

For the design engineer, this high-temperature torch opens up immense possibilities in the application of various coatings, particularly those of very high melting point such as carbides and other ceramics. The use of coatings on a basic material is steadily growing in many industries, providing an answer to a number of the engineering problems where surfaces are required to meet specific applications. The use of coatings are in many cases limited by the very high temperatures needed and the equipment thus required, but this new process should offer a potential solution.

It has been reported that intricately-shaped nozzles for rockets may be easily made by depositing powdered tungsten or other suitable refractory metal on a spinning mandrel, and after coating, etching away the mandrel to leave a deposit 0·010 in. thick in the shape of the nozzles.



Close-up view of the Plasma-flame torch developed by the Thermal Dynamics Corporation.

The hardest materials, such as titanium carbide, and even concrete, may be easily cut by the plasma stream. Metallic oxides which have high vapour pressures can be readily applied, the surface of the metal to be sprayed being kept under 260 deg. C. and the plasma process has the advantage of a porosity of between one-half and one-third of a flame-sprayed coat of the same material.

The accompanying table gives typical operating data for the Plasma-flame system developed by the Thermal Dynamics Corporation. The unit may be operated while submerged in liquids such as water and kerosene. Any mixture of gases may be used and various nozzle sizes are available. Gas flow rates and power outputs can be adjusted over a wide range, thus permitting almost any combination of temperature and flow rate.

Typical operating data for a plasma torch

Gas type	$\%H_2$ in N_2	Gas flow (s.c.f.h.)	Power supplied (d.c. kW.)	% d.c. power to gas	Average gas temp.	
					°F.	°C.
N_2	0	30	25	65–70	18,000	9,980
N_2	0	100	25	65–70	9,000	4,990
N_2	0	200	25	65–75	7,500	4,145
N_2	0	80	50	65–70	17,000	9,435
H_2	100	150	8	70–80	4,500	2,480
H_2	100	150	25	65–80	6,200	3,425
H_2	100	200	70	65–80	16,000	8,870
N_2H_2	45	80	40	65–80	18,000	9,980
A	0	50	25	40–60	25,000	13,870
He	0	50	25	40–60	32,000	17,760

DYNAMIC DESIGN WITH RUBBER

The Research Association of British Rubber Manufacturers recently organised a symposium on the design of rubber engineering products. Main points contributed by the speakers taking part are reported here

by J. R. SCOTT, Ph.D., M.Sc., F.R.I.C., F.Inst.P., F.I.R.I.*

RUBBER is being used to an increasing extent as an engineering material, that is, as a component of structures subject to stresses and strains, its particular function being to isolate important parts of the structure against shocks and vibrational stresses. Modern trends, especially in transport by land, sea and air, even in outer space, involve ever more severe operating conditions and require more exacting performance.

If rubber is to meet this new challenge, the rubber components of engineering structures must be designed with the same care and on the same basis of established theory and data as components of steel or other conventional engineering materials. It must be confessed, however, that hitherto this has not always been the case, and the blame cannot be laid entirely on the engineer, because the necessary theoretical principles and data simply have not been available. This arises largely because of the fundamentally different and more complex mechanical behaviour of rubber as compared with normal engineering materials.

In the first place, rubber has a vastly greater range of reversible (or substantially reversible) deformations than a metal, and hence the familiar Hooke's law or proportionality between stress and strain can no longer be used. This is well seen, for instance, in calculating the stress/strain relation for a compressed rubber block (see Fig. 2) where it has been necessary to introduce complex "shape factors" to allow for the very considerable departure from stress/strain proportionality. Moreover, rubber is never perfectly elastic; its deformations always involve a viscous component, that is, a component 90 deg. out-of-phase with the stress, so that its effective elastic modulus (E^*) is really a complex represented by the equation:

$$E^* = E_1 + i\,E_2$$

where E_1 and E_2 are the moduli corresponding to the in-phase and out-of-phase stress components; Fig. 3 shows this relationship in the form of a vector diagram.

Again, the whole visco-elastic behaviour is to a greater or less extent dependent on temperature and on the rate (or frequency) of the deformation, so that if, for instance, temperature is lowered, the rubber at some stage becomes stiff and leathery and ultimately rigid, and similarly, if we attempt to deform the rubber extremely quickly, it will appear very stiff or even rigid (see Fig. 4).

Finally it must be realised that "rubber" is a generic term covering a vast range of types having widely varying properties, and the selection of the best type for any given use is a matter requiring the closest collaboration between the engineer, as the user, and the rubber technologist.

It is clear, therefore, that the rubber technologist has a great deal to do in providing the basic information on the properties of rubbers and their dependence on temperature and frequency, and in formulating the principles that govern the correct design of rubber components.

Prominent among the investigations of this subject have been those of the Research Association of British Rubber Manufacturers, who have, over many years past, published an important series of reports and papers. In order to help in bringing this work to the notice of engineers and others concerned with engineering design in rubber, the association recently organised a three-day symposium on Dynamic Design with Rubber, held at the Shropshire Adult College, near Shrewsbury. The basic idea was to bring together engineers and rubber technologists in a residential college providing opportunities for informal discussion and to arrange a series of lectures which between them would present a comprehensive picture of the problems involved and the methods available for solving them.

On the opening day of the symposium, the first lecture was given by Mr. W. M. Buchan, head of the technology department, Shrewsbury Technical College, who spoke on "The Production Engineer's Viewpoint"; this introduction served admirably to define the scope of the problems

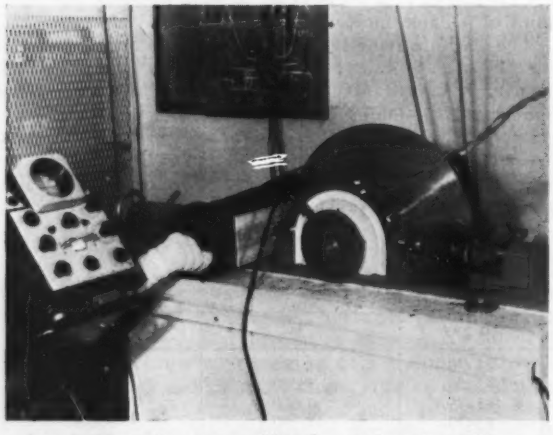


Fig. 1. Dynamic test machine for engineering rubbers, developed by the Research Association of British Rubber Manufacturers. An eccentric on the flywheel shaft applies a sinusoidal deformation to the rubber test-piece (contained in heat-insulated chamber); the amplitude of the resulting force cycle and the phase lag δ are measured by the cathode-ray tube.

* *Scientific adviser, Research Association of British Rubber Manufacturers.*

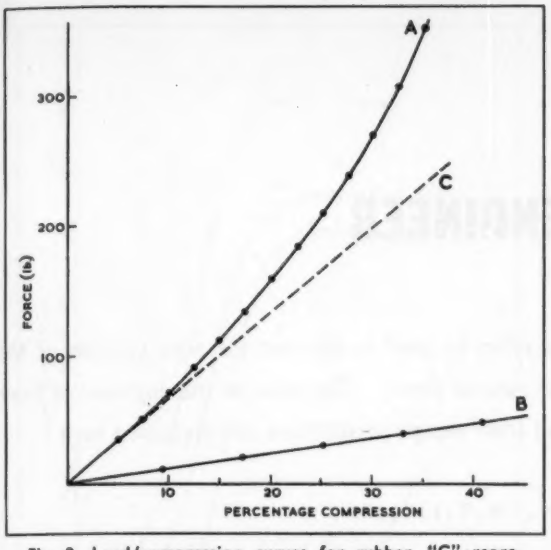


Fig. 2. Load/compression curves for rubber. "C" represents Hooke's law and "A" the actual force required. Curve "B" relates to shear instead of compression, and shows stress proportional to strain.

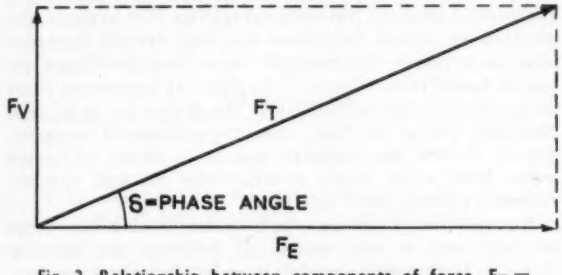


Fig. 3. Relationship between components of force. F_E = elastic (in-phase) component, corresponding to E_1; F_V = viscous (out-of-phase) component, corresponding to E_2; F_T = total force, corresponding to E^*. δ is the phase lag between total force and strain.

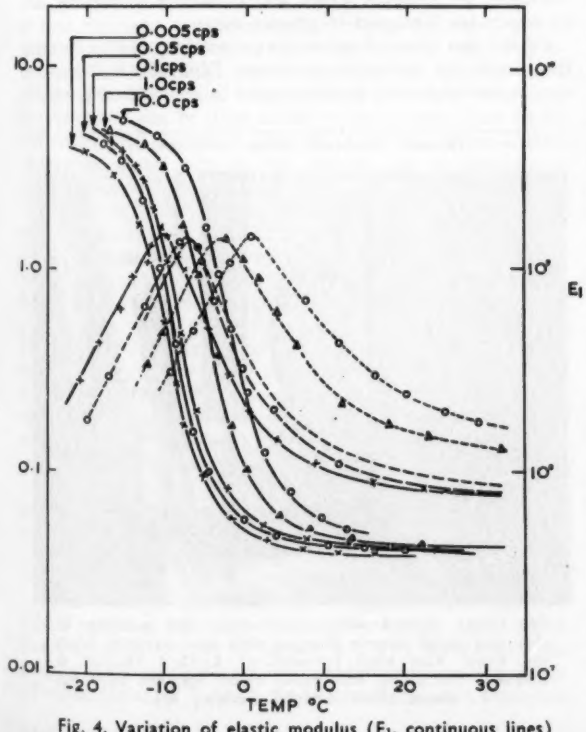


Fig. 4. Variation of elastic modulus (E_1, continuous lines) and viscous "loss factor" (E_2/E_1 or tan δ, broken lines) with temperature and frequency.

that were to be discussed in more detail in later sessions. This was followed by a lecture by Mr. A. R. Payne, of the Research Association of British Rubber Manufacturers, describing his work on "Shape Factors and Functions"; in this he demonstrated how the force required to compress a rubber block (with end faces bonded to metal) is simply the product of the shear modulus of the rubber and a "shape function" dependent essentially on the dimensions of the block and the applied deformation. This function is independent of the frequency and the temperature, and applies equally to the in-phase and out-of-phase components of the stress, though the constant in the function is dependent on the nature of the rubber.

On the afternoon of the first day, Dr. A. N. Gent, of the British Rubber Producers' Research Association, gave a lecture on "Some Design Problems in Engineering Applications". This described how certain specific problems in rubber engineering had been tackled and solved by the B.R.P.R.A., where work on this general subject is proceeding in parallel with that at the Research Association of British Rubber Manufacturers. In particular he discussed the design of rubber supports for civil engineering structures, such as bridges and aqueducts, as well as the design of rubber pads for railway tracks.

To open the second day's proceedings, Mr. Payne continued his account of R.A.B.R.M. work with a lecture on "Other Factors which Influence Design". This dealt in particular with the interdependence of temperature and strain-rate (or frequency) effects in the deformation of rubbers, where the author has recently shown that a simple relation holds for a great variety of materials and over a wide range of conditions, as, for instance, from high-speed vibrations to long-period creep; this relation, incidentally, applies to dielectric loss as well as mechanical deformation. This lecture also touched on some of the consequences of the non-linear stress/strain relationships of rubber and the causes of this non-linearity.

The general theme of the symposium then turned to the problem of measuring the properties required by engineers as design data. The first lecture on this aspect was by Mr. D. Bulgin, of the Dunlop Research Centre, on "Laboratory Measurements of the Engineering Properties of Rubbers", in which the general nature of the problem was defined and a more detailed account given of methods used at the Dunlop Research Centre for measuring the elastic and viscous components of deformation and for investigating departure from linearity. Mr. R. H. Norman (R.A.B.R.M.) spoke on "Providing Design Data", briefly surveying the principles underlying the various available test methods such as forced vibrations (with or without resonance), free vibrations, wave propagation, and creep and stress relaxation tests.

To round off the symposium, Messrs. Buchan and Payne gave a joint discussion on "Collaboration between the Rubber Technologist and the Engineer", in which they set out in very clear fashion the ideal procedure for tackling a design problem in rubber engineering.

On the third day the members of the symposium visited the R.A.B.R.M. laboratories, where they saw demonstrations of the apparatus used for the investigations on the visco-elastic (or in rubber jargon "dynamic") behaviour of rubber (see Fig. 1) and other pieces of testing equipment, some of which have recently been developed by the Research Association, of special interest to engineers.

Bookings for the symposium so far exceeded expectations that it was decided to organise a repeat early in December. The excellent attendance and the active discussions—both formal and informal—that developed between the engineers and technologists who attended leave no doubt that this symposium has fulfilled a most useful purpose in promoting the application of rubber in engineering construction.

NYLON YARN FOR THE ENGINEER

Nylon yarns can now often be used in applications once considered the province of metals or natural fibres. The value to the engineer of their unique properties and their design possibilities are discussed here

by J. BUCHAN, A.T.I.*

TO the design engineer nylon textile yarns are a rewarding subject for investigation. Their unique combination of properties has extended remarkably the limits of textiles. Textiles are now being used where only a few years ago they would not have been considered, and there is every indication that the penetration of textiles into what was thought to be metals' province is likely to be considerable.

Nylon offers scope to the engineer in three distinct ways. The first (most immediate as well as most obvious) is to obtain greater efficiency by simply using nylon in place of conventional textile materials. The advantages of nylon for certain filtration processes, for example, are already widely appreciated, while nylon belt drives can sometimes overcome power transmission problems.

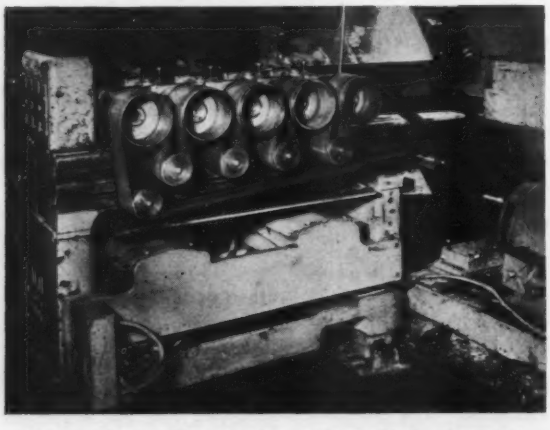
The second, a logical development from the first, is to enable certain machinery and installations to be redesigned more powerfully, compactly or efficiently by taking full advantage of nylon's great toughness and durability. The entire design of the car in which Donald Campbell will make his attempt on the world land-speed record in 1960 is focused on the tyres, which are expected to be nylon-corded. It is probably true to say that without nylon to give the rugged, compact and light-weight tyres necessary for high-speed performance, the development of jet aircraft would have been seriously hindered.

The third, and by far the most intriguing, way is to enable a completely fresh approach to be made to many old problems, made possible because nylon has capabilities far beyond those of conventional textiles. For example, the problem of vehicle suspension has been freshly examined and, as a result, "air springs" have been developed for use in heavy road vehicles. This form of suspension relies on a nylon-reinforced bellows or diaphragm for its success. Similarly, during the Suez crisis, the problem of transporting oil by sea was reviewed and, as a result, oil barges made from nylon fabric proofed with oil- and weather-resistant rubbers were developed.

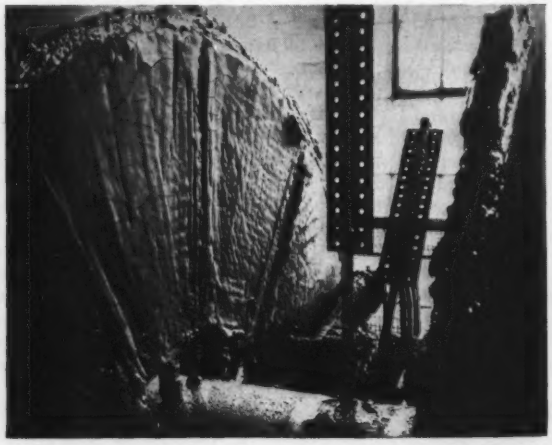
Some of the properties which enable nylon textile yarns to fulfil such a wide variety of functions are listed in Table 1. High tensile strength is an outstanding advantage, but scarcely less important are nylon's very great powers of energy absorption, its high resistance to the effects of fatigue and abrasion and, often, its high wet strength, resistance to chemical attack and immunity to rotting, all of which are discussed in greater detail.

Of the two types of nylon yarn manufactured in Britain specifically for industrial purposes, Type 300 is the yarn used most extensively at the present time. Type 600, which

* Textile development department, British Nylon Spinners Ltd.



Output of this 1,000-r.p.m. borer was doubled when fitted with nylon and chrome-leather transmission belt in place of the original V-belts. Slippage which smashed tools has been eliminated. Cutting speed and depth of cut were increased by 50 per cent. Belt was made by Stephens Belting Co. Ltd.



Disc filter clothed with nylon solves the problem of cleansing water heavily charged with dust particles from the Ebbw Vale blast furnaces of Richard Thomas & Baldwin. The 12-oz. continuous nylon filament twill has about three months' working life.

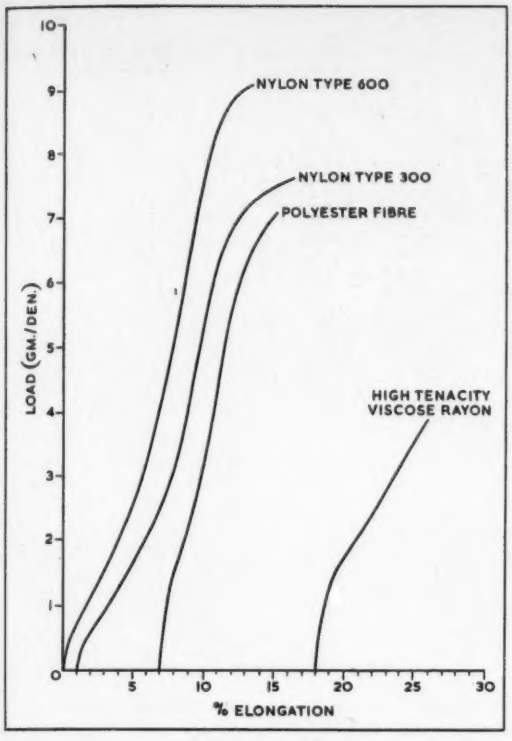


Fig. 1. Load-elongation curves for industrial textile yarns (rate of load application 0·5 gm./den./sec.).

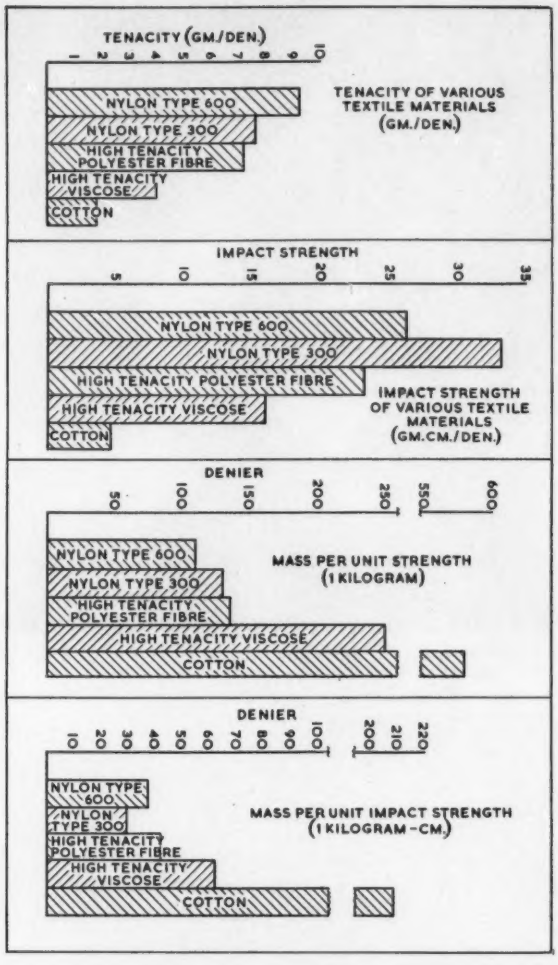


Fig. 2. Comparison of tenacity, mass and impact strength of nylon with other textiles.

is even stronger, was developed in 1956 principally for tyre cord and conveyor belting ducks, but is now beginning to be used more widely. Nylon may also be supplied as a staple material, i.e., a mass of relatively short filaments. Staple nylon can be used alone or mixed with other staple materials such as cotton, asbestos or staple rayon. Unless otherwise stated, data in this article refer to continuous filament nylon.

STRENGTH—The tensile strength of nylon yarn is normally expressed as tenacity and measured in grams per denier, denier being the weight in grams of 9,000 metres of yarn. (For example, a yarn of which 9,000 metres weighs 840 grams is described as 840 denier.) The strength of nylon yarns is far greater than that of conventional textile fibres. The breaking load of a nylon cloth is between two and four times that of a cotton cloth of the same weight, while a nylon rope has a breaking strain upwards of double that of a high quality manila rope of the same size. Table 2 shows how the tenacity of nylon compares with that of other fibres and steel.

From a practical point of view, this means that far greater strength can be obtained without any increase in weight or bulk; alternatively, weight and bulk can be reduced substantially without forfeiting strength. This is aided further by nylon's lightness in weight (see Table 3).

EXTENSIBILITY AND RECOVERY—Together with their low initial modulus and high breaking extension, nylon yarns have excellent powers of recovery. Fig. 1 shows how the load/elongation curves of nylon yarns compare with those of other fibres. In Table 4 the effects of repeated extension are correlated with powers of recovery and from this it can be seen clearly that although nylon is more extensible than other yarns it also has better recovery.

In instances where nylon's ability to extend readily under low loads is a disadvantage, the difficulty can frequently be overcome by the use of heat-stretched yarn. Heat stretching relies on the fact that nylon is a thermoplastic. The process has the effect of increasing the modulus of nylon (and improving its heat stability) to a degree dependent on three main variables, temperature of heating, time of heating and tension applied during heating. Heat-stretched nylon is used extensively for tyre cords.

ENERGY ABSORPTION—As a result of their combination of high tensile strength and extensibility, nylon yarns have very great powers of energy absorption—greater than those of any other textile yarns. A comparison with other industrial yarns is shown in Fig. 2. This ability of nylon to withstand very severe or repeated shock loads, because of its good elasticity, is a key to its success under many severe conditions. Practical illustrations which can be quoted include nylon rope, which is capable of holding at least three times the weight of a dropped load as high-quality manila rope of the same size, and nylon drop stamp belts, which have a life of over three times that of hair belts.

FATIGUE RESISTANCE—Good resistance to the effects of repeated flexing and bending is often one of the chief reasons why an engineer uses textiles, since in this respect they are far superior to most other materials. Nylon's fatigue resistance is outstanding, as illustrated in Table 5.

Clothed with 1½-oz. nylon, this vacuum filter delivers 8 lb. of dry matter per sq. ft. per hr. Used by West Kent Main Sewerage Board, it has a life of about 2,400 hours.

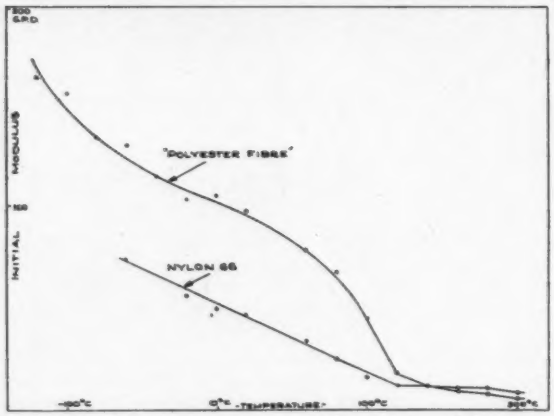
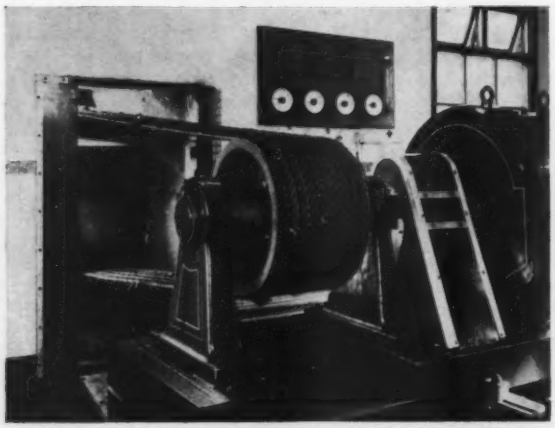


Fig. 3. Effect of temperature on the initial modulus of polyester fibre and nylon 66 high-tenacity yarns.



These cotton and nylon mixture ropes, operating a fan which exhausts air from a mine at Askern Main Colliery, have been in almost continuous use for two years, without need of adjustment.

TABLE 1. Some of the principal properties of high-tenacity nylon yarn

	Type 300	Type 600
Tenacity, dry, grams/denier	7·0	8·8
Tenacity, wet, grams/denier	6·3	7·9
Breaking stress, dry, ton/sq. in.	45	57
Breaking stress, wet, ton/sq. in.	40	51
Extension at break, dry, %	15–19	12·0–17
Extension at break, wet, %	16·5–20·5	13·5–18·5
Young's modulus, dynes/cm.²	$3–4 \times 10^{10}$	
Rigidity modulus, dynes/cm.²	$0·5 \times 10^{10}$	
Specific gravity	1·14	
Melting point	250°C.	
Moisture regain at 65% R.H. and 25°C.	4	

TABLE 2. Comparison of tenacity and breaking stress of nylon with other materials

	Tenacity (gram/denier)	Breaking stress (ton/sq. in.)
Nylon type 600	8·8	57
Nylon type 300	7·0	45
Polyester fibre, high tenacity	6·0–7·0	47– 54
Rayon, high tenacity	3·5–4·5	30– 39
Steel	0·4–3·3	18–147
Cotton*	3·0–6·0	25– 51

** Figures for cotton are based on fibre properties. Figures for cotton yarn will be lower.*

TABLE 3. Average specific gravity of various materials

Polyethylene (Courlene X3)	0·95	Cotton	1·50
Nylon	1·14	Viscose rayon	1·52
Wool	1·32	Polyvinylidene chloride (Saran)	1·72
Polyester	1·38	Glass	2·56
Hemp	1·48	Asbestos	2·10–2·80
Jute	1·48	Steel	8
Linen	1·50		

TABLE 4. Recovery under load of industrial yarns

	Nylon, type 600	Rayon, high tenacity	Polyester fibre, high tenacity
Denier	840	1,650	4 × 250
Breaking load, lb.	16·5	16·0	16·0
Extension caused by 10 × 5 lb. load cycles, %	5·0	3·6	2·25
Amount of extension recovered after 10 × 5 lb. load cycles, %	95	38	84

ABRASION RESISTANCE—Nylon's resistance to abrasion is far better than that of any other textile. While it is difficult to relate abrasion resistance to performance during use, various laboratory tests give a reasonable indication of the comparison between one fibre and another. Results obtained when continuous-filament nylon was compared with other continuous-filament materials and when staple nylon was compared with other staple materials are shown in Table 6. For both comparisons, comparable cloths were used. While the warp break figures are primarily a measure of the abrasion resistance of the warp, they serve also to indicate the protection given by the weft to the warp. Even ignoring this aspect, nylon is 50 per cent better than its closest rival and nearly four times more resistant than cotton.

EFFECT OF MOISTURE—Nylon is fortunate in not being seriously affected by moisture. Complete wetting out causes a loss of from 8-10 per cent in the tensile strength of high-tenacity yarns. Since there is a compensating increase

*TABLE 5. Fatigue life of industrial yarns**

	Denier	Breaking load unflexed (lb.)	Breaking load after 100,000 cycles (lb.)	Strength retained after 100,000 cycles (%)	Breaking load after 250,000 cycles (lb.)	Strength retained after 250,000 cycles (%)
Nylon, type 300	2/4/210	27·12	23·54	87	20·02	74
Nylon, type 600	2/840	28·21	26·80	95	22·48	80
Rayon, high tenacity	2/1650	25·69	19·14	75	14·65	57
Polyester fibre, high tenacity	2/4/250	26·72	13·93	52	10·89	41

* *Scott flexer, pulley diameter, $\frac{1}{8}$ in., pulley loading 80 lb. cords moulded into rubber.*

*TABLE 6. Comparative abrasion resistance of textile materials **

Weft	Warp	Construction	Rubs to first weft thread broken	Rubs to first warp thread broken
Rayon, 250 denier	205 denier nylon	4 end sateen 54 ends, 88 picks	1,935	5,463
Polyester fibre, 250 denier	205 denier nylon	4 end sateen 54 ends, 88 picks	6,396	9,450
Nylon, 210 denier, type 300	205 denier nylon	4 end sateen 54 ends, 96 picks	9,965	14,733
Rayon, 1/20s cc	205 denier nylon	4 end sateen, 54 ends, 88 picks	1,800	4,530
Peruvian cotton, 1/20s cc	205 denier nylon	4 end sateen, 54 ends, 88 picks	2,560	6,230
Polyester fibre, 1/20s cc	205 denier nylon	4 end sateen, 54 ends, 88 picks	6,150	13,370
Nylon 1/20s cc	205 denier nylon	4 end sateen 54 ends, 88 picks	9,740	27,000

* *Martindale abrasion tester; grade O emery paper.*

*TABLE 7. Wet strength of industrial yarns**

	Denier	Breaking load (lb.)		Strength lost (%)	Extension at break (%)		Increase in extension at break (%)
		Dry	Wet		Dry	Wet	
Rayon, high tenacity	1,650	13·6–16	8·5–11·8	26–37	9–14	21–27	230–190
Nylon, type 300	210	3·9	3·5	10	15	16·5	10
Nylon, type 600	840	16·6	15·2	8	13	14·5	11·5
Polyester fibre, high tenacity	250	4·1	4·1	Nil	10·7	10·7	Nil

* *Immersed for five minutes, tested immediately.*

in the extension at break (see Table 7), the powers of energy absorption remain virtually unaffected. There is little or no effect on nylon's flex strength or fatigue resistance, and although there is some loss of abrasion resistance nylon still remains superior to other textile yarns. It regains its original properties completely on drying out.

RESISTANCE TO ROTTING—Nylon is completely rot-proof and is not harmed by moulds, fungi or bacteria. Soil burial tests have shown that after twenty-one days' burial, during which time it was exposed to attack by flourishing anærobic and aerobic bacteria and fungi, nylon fabric retained 95 per cent of its original strength while a control fabric of cellulosic fibres was completely rotted away.

EFFECT OF TEMPERATURE—The tenacity of nylon yarn is unaffected by low temperatures. Test results on yarn exposed to −80 deg. C. were the same as those obtained with yarn at normal temperatures.

Nylon yarn melts at about 250 deg. C. With temperature increases up to about 100 deg. C., the initial modulus decreases slowly and linearly as shown in Fig. 3.

Nylon is remarkably stable to wet heat and is not degraded seriously by steam. Yarn exposed to steam at 100 deg. C. for six days shows little change in tenacity.

DIMENSIONAL STABILITY—As nylon is a thermoplastic it can be heat-set. Nylon fabrics which have been properly set do not shrink or stretch out of shape. Good dimensional stability at raised temperatures can be achieved by ensuring that heat-setting is carried out at a somewhat higher temperature than is likely to be experienced in use.

FLAME RESISTANCE—Nylon is inherently flame-proof. It does not blaze when brought into contact with a flame but fuses, forming a round, hard bead which recedes from the flame. It should be noted, however, that certain dyes and finishes which are used occasionally may make nylon inflammable. Nylon mixture fabrics have a flame-resistant intermediate between that of nylon and the other fibre or fibres present.

RESISTANCE TO CHEMICALS—In general, nylon is highly resistant to chemical attack. It is unaffected by aliphatic hydrocarbons (e.g., petrol, mineral oils), aromatic hydrocarbons (e.g., benzene, xylene), ethers, esters (e.g., amyl acetate, vegetable oils), ketones (e.g., acetone), alkyl halides and mercaptans. Similarly, solutions of inorganic solvents, sodium hydrosulphate, liquid ammonia, sulphur dioxide and cuprammonium solutions have no effect.

Caustic alkali solutions of up to 20 per cent at room temperatures have no effect.

Nylon will withstand the action of only dilute mineral acids and is attacked by concentrated acids at a rate dependent on the concentration and temperature. For example, 10 per cent hydrochloric or sulphuric acids will cause a 25 per cent loss in strength after four-and-a-half days. A 12 per cent nitric acid will cause a 25 per cent loss in strength after forty-seven days.

Phenols, particularly phenol itself, meta-cresol and cresylic acid are solvents for nylon. In low concentrations in water the effect is usually small, though some shrinkage may result.

RESISTANCE TO INSECTS—Nylon is virtually immune to attack by insects. There is not a known instance of any insect deriving sustenance from nylon, but some insects may cut their way through fabrics if trapped within them. They may also attack nylon fabrics which have been treated with attractive substances.

New Ideas for Fail-Safe Mechanisms

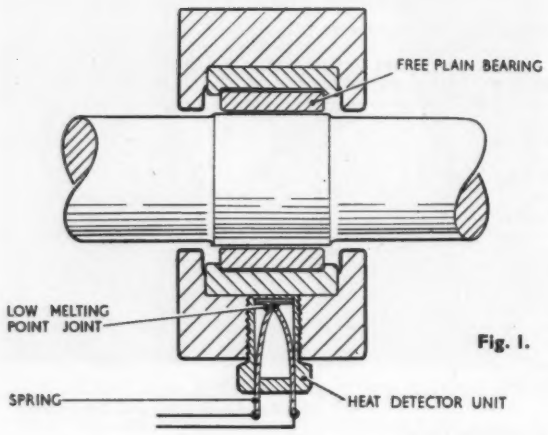


Fig. 1.

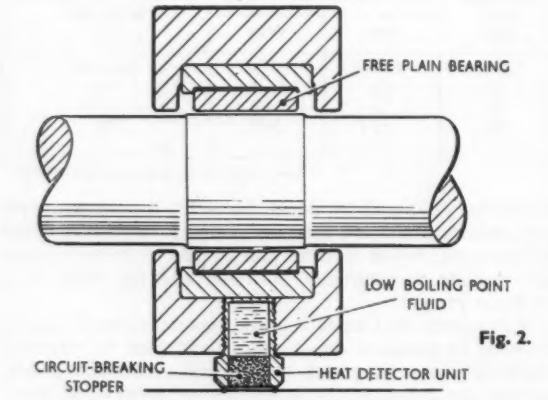


Fig. 2.

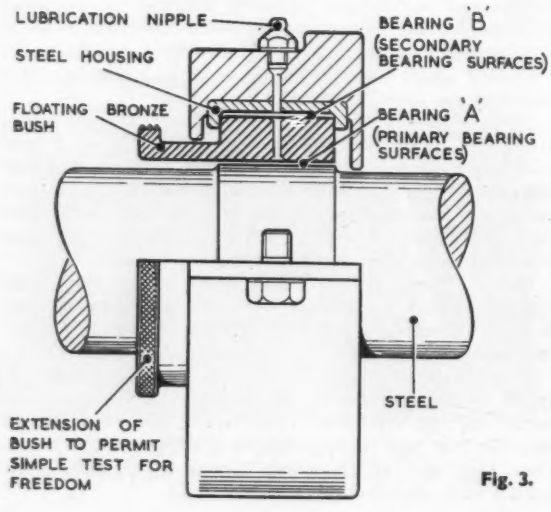


Fig. 3.

A NUMBER of new suggestions for the design of fail-safe mechanisms, originally intended for aircraft applications but believed to have many other fields of use in engineering, were discussed in a recent paper delivered to the Royal Aeronautical Society by R. Hafner, F.R.Ae.S. Although the perfectly-designed and -made mechanism should not fail within its normal expectancy of life, faults in manufacture, poor assembly and many other factors make certain kinds of safety provision essential. Certain kinds of failure occur early in the life of a component. Other more sinister types of fault defy detection for long periods, then cause sudden failure. A considerable part of the paper was devoted to this latter type of fault. In the lecturer's view it appeared desirable to make provision for early detection of such faults in addition to duplication of load-carrying components to ensure "fail-safe".

In the operation of equipment it is often essential that:

1. A mechanism continues to function for a while even though something has failed.
2. Some kind of warning be given upon failure.
3. The mechanism both continues to function after failure has occurred (i.e., fail-safe) and embodies features that facilitate early detection.

Among a number of ideas put forward to illustrate the way of thinking he recommended are those illustrated. Figs. 1 and 2 represent in a diagrammatic way a form of fault detector which operates throughout the life of a component and provides a warning when failure occurs. Bearing failures are usually accompanied by an increase in friction and a rise in bearing temperature. This kind of fault can remain undetected unless a warning device is fitted. Two types of bearing temperature indicator are shown applied to a plain bearing. Fig. 1 shows a screwed plug containing a low melting point joint which, when melting, breaks an electric circuit.

Fig. 2 shows a similar device, but in this case the plug contains a low boiling point liquid and a stopper which acts as a circuit breaker. A number of devices such as these would be connected to a warning indicator. In Fig. 3 is shown a "fail-safe" device embodied in a bearing. A floating bronze bush, which is free to rotate in a steel housing, also allows rotation of the shaft which passes

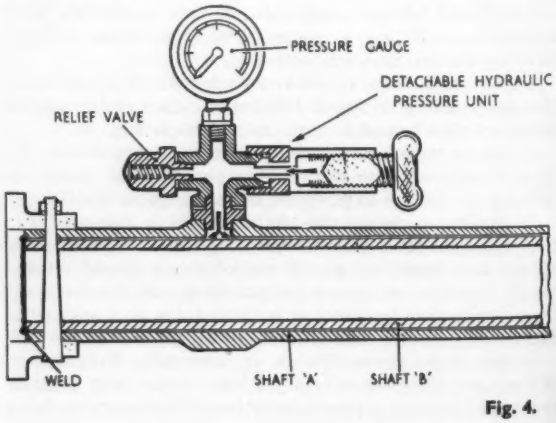


Fig. 4.

through it. Should seizure of the shaft in the bush occur, the bush will rotate in the steel housing. To enable inspection to be carried out without dismantling, the bronze bush is provided with an external knurled collar for checking freedom of rotation.

In Fig. 4 a device is shown which will fail-safe and, in addition, provide means for the early detection of failure. Two tubular shafts, A and B, of approximately equal torsional strength and stiffness are telescoped into one another, sealed at their ends and bolted to coupling members or the like. The outer shaft carries a nipple to which can be attached a crack detector in the form of a hydraulic pressure unit. Normally both shafts share approximately equally in the transmission of torque. Should one of the shafts develop a crack or fracture, then the other is capable of transmitting the whole torque for a given time.

CONTRIBUTIONS INVITED

Readers are invited to submit for publication in "Designer's Notebook" details of ingenious devices and mechanisms which could be used more widely than in their original application.

Contributions, which will be paid for, should preferably be about 300 words in length and be accompanied by an explanatory diagram or sketch. The designer's name will be published, unless requested otherwise.

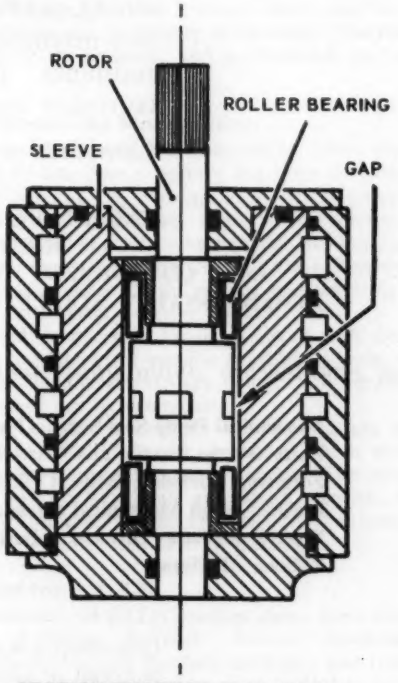
Contributions should be sent to The Editor, "Engineering Materials & Design", Drury House, Russell Street, London, W.C.2.

A Rotary Hydraulic Control Valve

IN order to overcome the "break-out" force associated with high-pressure piston-type valves, and also to eliminate the dynamic loads brought about by the flow of hydraulic fluid through the valve, Boulton Paul Aircraft Ltd. have developed and patented a rotary valve.

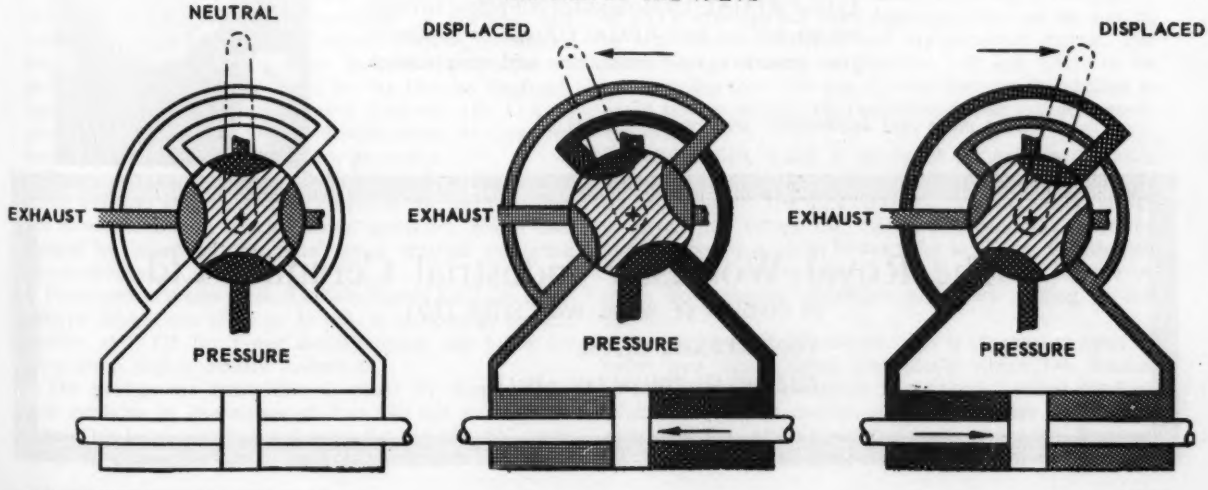
It will be seen from the diagram that this rotary valve consists essentially of a central rotor which is held within an outer sleeve by roller bearings so that there is a gap between the rotor and the sleeve which, although exaggerated in the diagram, is actually 0·00025 in. This gap keeps the valve leak down to a satisfactorily low value, but is sufficient to prevent contact between the two surfaces. This contact, together with "silting" is the cause of objectionable "break-out" force which is a common feature of piston-type valves.

By careful shaping of the fluid porting in the valve, it has been possible to make use of the momentum of the fluid passing through the valve to overcome the problem of dynamic load and produce a stable, low-force system. In addition, owing to the overall arrangement, the possibility of a hydraulic lock is completely eliminated. The rotary control valve can be operated manually, through a differential lever assembly providing its own mechanical feed-back or, alternatively, due to its negligible "break-out" torque, it is well suited for operation by a torque motor. For this reason it is particularly suitable for use where electrical operation is encountered in such applications as autostabilisers, variable gearing, etc.



SECTION THROUGH THE VALVE

OPERATION OF THE VALVE



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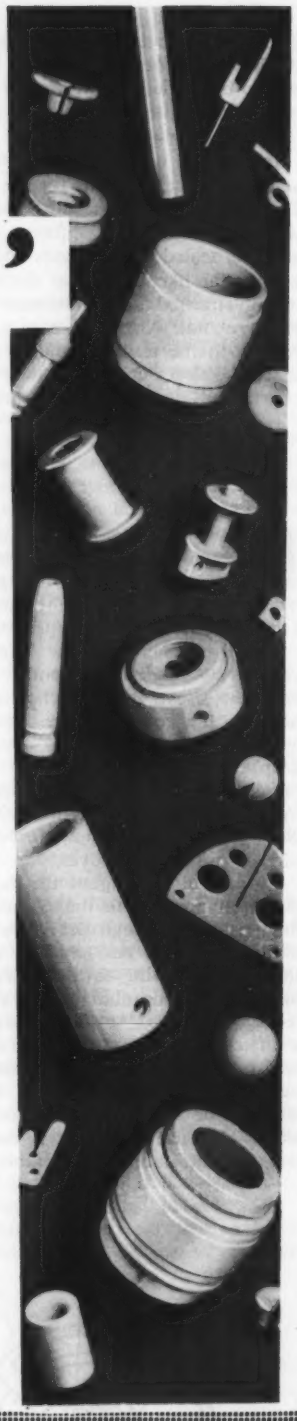

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NEW DEVELOPMENTS AT PLASTICS SHOW

FROM OUR OWN CORRESPONDENT

MODIFICATION and improvement of existing plastics materials was the keynote of the 8th National Plastics Exposition held in Chicago. Sponsored by the Society of the Plastics Industry Inc., the show was attended by about 30,000 people, who visited over 200 individual exhibits and attended the concurrent technical conference.

No brand-new polymers were announced, but there were a number of important new developments in plastics materials and processing techniques of particular interest to designers and engineers.

ALKYD MOULDING COMPOUNDS—Unusually high retention of insulation resistance after exposure to moisture and heat is the major benefit of four new alkyd compounds of the Allied Chemical Corp. The compounds are (1) glass fibre-filled impact-grade compound for compression moulding; (2) two free-flowing granular types, one compounded for plunger moulding, the other for fast-cure compression moulding; and (3) a putty-type moulding compound. Insulation resistance values of 25,000 to 30,000 megohms (after 24 hr. exposure to 95 per cent relative humidity at 70 deg. C.) drop only to 15,000 to 20,000 megohms for two of the compounds after sixty days at 95 per cent relative humidity and 70 deg. C.; values for the other two compounds drop to 5,000 to 10,000 megohms after sixty days of the same type of exposure. Other properties of the compounds are similar to those of conventional alkyds.

EPOXY SPRAY GUN—Rapid and uniform spraying of quick-curing epoxy resin systems, either with or without chopped glass reinforcement, can now be done with a new Union Carbide epoxy spray gun. This technique, previously used only with polyester resins, permits economical production of large reinforced plastics structures, such as boat hulls. The gun is designed to meter the resin and catalyst so that mixing takes place within the heated gun barrel and the mixture is sprayed under positive pressure.

COLOURED PHENOLICS—A new moulding compound using as its resin binder a copolymer of phenolic and melamine resins combines the colourability of melamines with the lower cost and other beneficial properties of phenolics. A speciality material by the Plastics Engineering Co., the moulding compound costs (in the U.S.A.) about 34 cents/lb., as compared with about 45 cents for melamines and about 20 cents for phenolics.

FILMS OF PLASTICS FOAMS—Both polyethylene (higher and lower density) and polystyrene foams in the form of films are now available in developmental quantities. Major uses should be based on the films' good thermal insulating characteristics.

Foam polyethylene films (Ludlow Papers Inc.) are available in thicknesses of 16 to 35 mil. at an average specific gravity of 0·375 for lower density resins and 0·426 for films from higher density materials.

The polystyrene foam film is made by Koppers Co. and available in thicknesses of 7 to 100 mil. at two densities. One large volume application for the material seems to be in disposable hot or cold drink cups.

Both the polyethylene and polystyrene films are vacuum formable.

NYLON SHEET AND FILM—Commercial production of nylon (type 6) sheet in widths up to 40 in. and thicknesses of 0·005 to 0·060 in. and film in widths up to 60 in. and thicknesses down to 0·0005 in. was announced. The sheet, shown by Chicago Moulded Products Corp., can be transparent or translucent, depending on thickness. The film can be transparent or coloured, and is marketed by Ludlow Papers Inc.

Anodise Finish for Magnesium

A clear anodic coating for magnesium alloys that can be applied in less than a minute has been developed by the Dow Chemical Co. Previously, designers requiring a metallic look for magnesium products had to use clear lacquers or varnishes over the bare metal. However, greater corrosion resistance is now obtained by using these coatings over the new anodise finish, which, because it is clear, allows the base metal to show through.

If required, lacquers or varnishes tinted with dyes can be applied over the clear anodise to obtain a wide variety of coloured metallic effects. The colours are durable and are not washed out by detergents.

The clear anodise treatment is a modification of the standard Dow No. 17 anodic treatment which normally produces yellow or green opaque deposits. The anodising baths for the two treatments are almost identical, except that 40 volts are used for the clear treatment as compared to 70 to 90 volts for the No. 17 treatment.

Wider Use for P.T.F.E.

The desirability of p.t.f.e. coatings stems from their low coefficient of friction, flexibility, chemical resistance, low moisture absorption and excellent durability and resistance to heat. Formerly, these coatings were limited to materials that could withstand the high temperatures (more than 370 deg. C.) required for sintering. However, a new family of p.t.f.e. coatings has been developed that can be applied to non-metallic materials and heat-sensitive metals. The new coatings (known as Emralon 310 and 320) can be cured at less than 150 deg. C. and thus can be applied to wood, rubber, plastics, light metals and other materials sensitive to heat.

Emralon 310, which is produced by Acheson Colloids Co., is a dispersion of low-friction p.t.f.e. in a durable phenolic binder. The dispersion is a two-part system which is mixed just before use. Spray application is preferred and the coating is cured in one hour at 65 deg. C. Emralon 320 is an air drying coating and is designed for use on more heat-sensitive materials or where baking is not practical.

Development of the new coatings is expected to open up many new applications, particularly where low friction or high corrosion resistance is required. Typical products where the coatings can be used to advantage are moulds, extrusion dies, gaskets and bearings, conveyors, firearms, playground slides, skis, ice-cube trays and many others.

EMD 522 for further information

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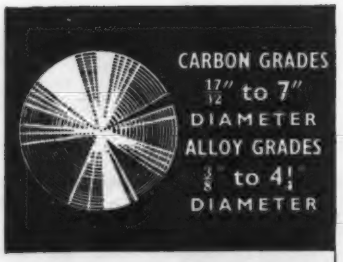
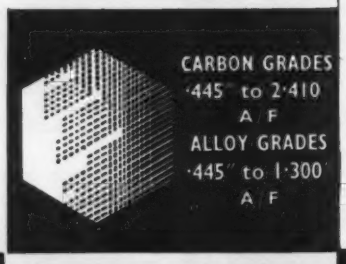
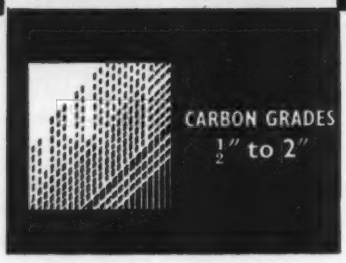
BRIGHT STEEL BAR

REQUIREMENTS







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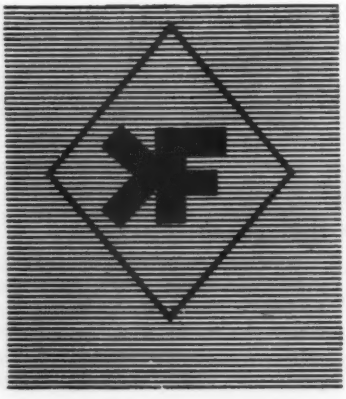

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STAYBRITE STAINLESS STEEL

FCB (T) * —fulfilling BS. En58G

Engineering Materials and Design
DATA SHEET No. 10

Physical Properties

Availability	Bar, sheet and strip Forgings and stampings Castings
Nominal Composition	0·08% C, 0·6% Si, 1·5% Mn. 17·5% Cr, 12·0% Ni, 0·8% Cb
Structure	Austenitic (non-magnetic)
Density	0·286 lb./in.³
Specific gravity	7·94
Melting Point	1,430 deg. C. (approx.)
Specific Heat	0·12 cal./gm.°C.
Coefficient of Thermal Expansion	(20/100 deg. C.) 0·000016 (20/700 deg. C.) 0·000019
Electrical Resistivity (at room temp.)	72 microhms-cm.

Mechanical Properties

U.T.S. (at room temp.)	91,000 p.s.i.
0·1% Proof (at room temp.) ...	32,200 p.s.i.
Elongation (at room temp.) ...	59%
Modulus of Elasticity (at room temp.)	29·35 p.s.i. × 10⁶
Brinell Hardness (at room temp.)	175
Izod Impact	50 ft./lb.
Scaling Index at 750 deg. C. ...	1·5 mgm./cm.²—after 7 cycles 6·0 mgm./cm.²—after 7 cycles
Max. Service Temperature ...	800 deg. C.
Heat Treatment for Hot Working	Start 1,150–1,200 deg. C. Finish 900 deg. C.

Room temperature mechanical properties after exposure (without stress) at a temperature of 650 deg. C.

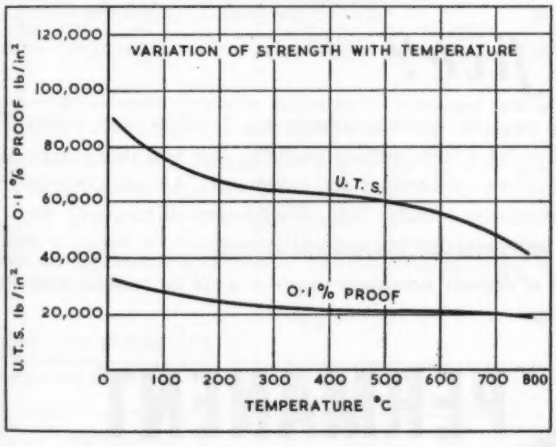
Exposure	U.T.S. (p.s.i.)	Elongation (%)	Izod Impact (ft. lb.)
2 days	99,600	52	85, 89, 90
2 weeks	99,000	50	73, 84, 72
3 months	94,000	54	101, 100, 102
1 year	95,000	51	56, 57, 58
2½ years	90,000	48	39, 38, 37

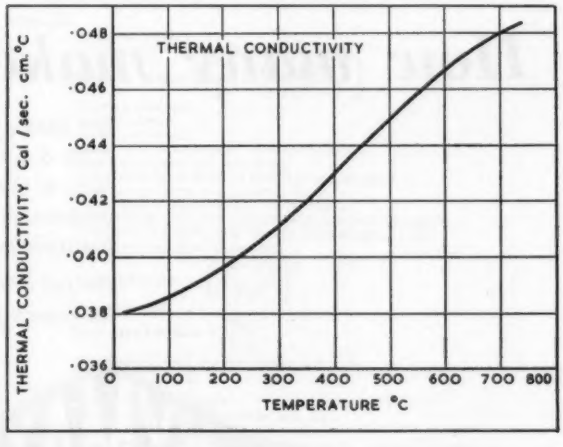
Softening	Quick cool from 1,050–1,100 deg. C.
Weldability	Very good. No heat treatment required.
Forgeability	Good (hot and cold)
Machinability	Fair
Corrosion Resistance	Excellent

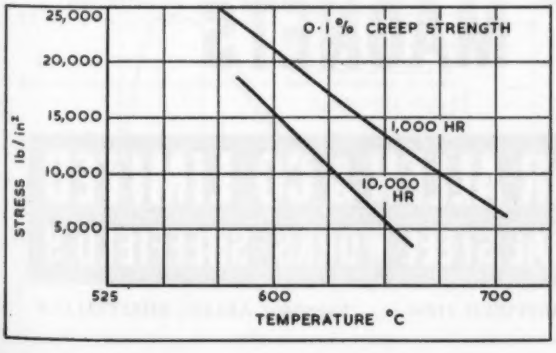
Fatigue Limit (Wohler test)

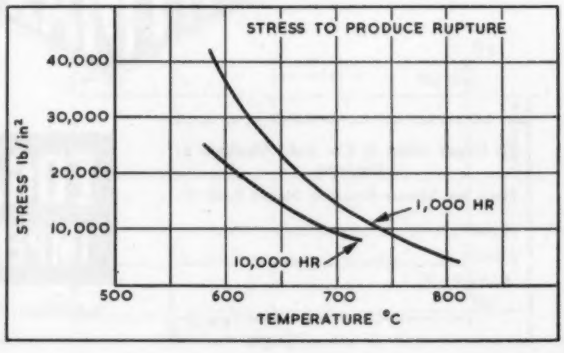
Room Temp.	30 × 10⁶ cycles. 43,700 p.s.i.
400 deg. C.	100 × 10⁶ cycles. 35,900 p.s.i.
500 deg. C.	„ „ „ 31,400 p.s.i.
600 deg. C.	„ „ „ 29,100 p.s.i.
650 deg. C.	„ „ „ 24,000 p.s.i.

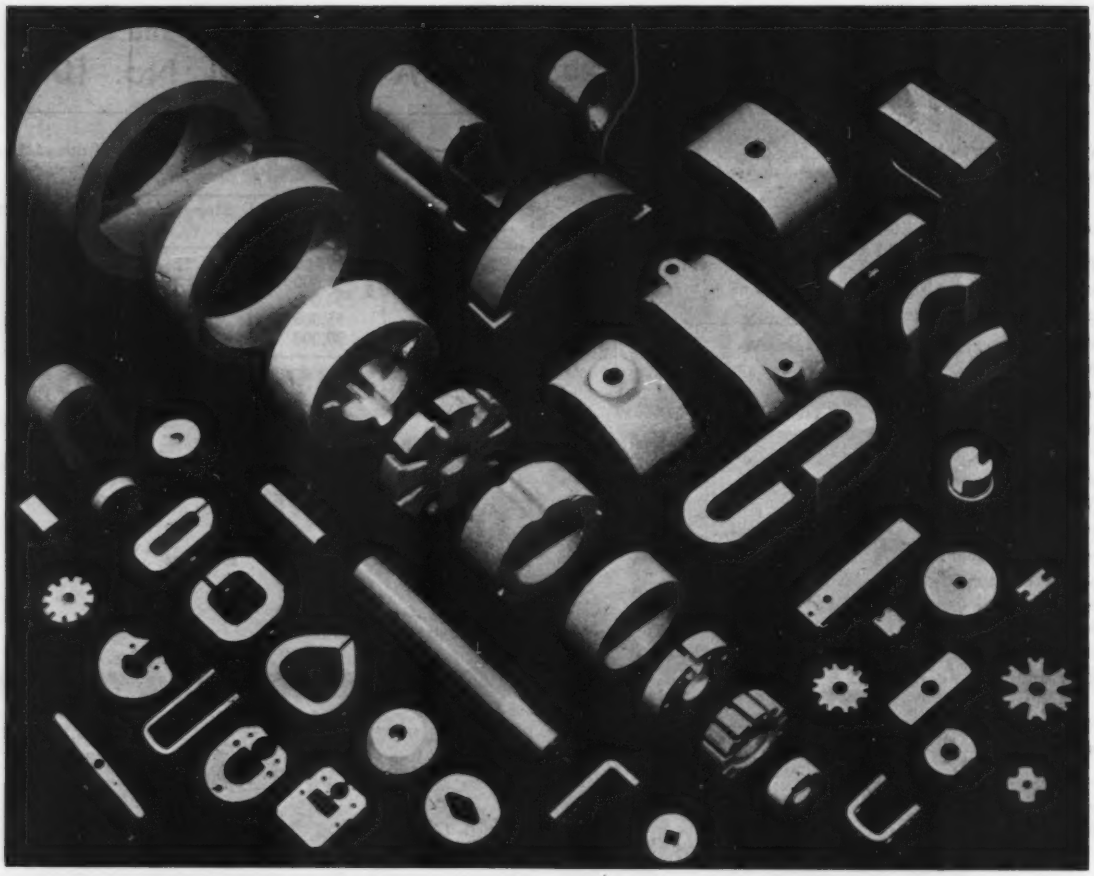
* *Made by Firth-Vickers Stainless Steels Ltd.*











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THERMAL STRESS IN SHORT UNIFORM CYLINDRICAL SHELLS

Engineering Materials and Design
DATA SHEET No. 11

Thin circular cylindrical shells stiffened at intervals along their length by bulkheads or frames are often used in engineering structures. When such shells are heated or pressurised, the thin shell tends to deform more than the thicker stiffening member and, consequently, discontinuity stresses are set up in the configuration. These are additional to those set up in the unstiffened shell.

This data sheet contains an analysis and indicates how the stress distributions due to arbitrary axial temperatures can be obtained, taking into account various forms of edge restraint.

Thermal Expansion Effects

For the free-ended cylindrical shell shown in Fig. 2 subjected to an arbitrary temperature distribution, T(x), it can be shown ([1] and [3]) that the shell radial deflection, w, is given by the equation

$$\frac{d^4w}{dx^4} + 4\beta^4 w = \frac{-E\alpha h}{Da}T(x). \qquad (1)$$

The solution of this equation enables the various stress-resultants and stress-couples in the shell to be determined. If we assume $T = \sum_{m=0}^{3} | F_m x^m |$ (see Ref. 3) the solution of Equation (1) is

$$w = C_1 \sin\beta x \sinh\beta x + C_2 \cos\beta x \cosh\beta x - C_3 T. \qquad (2)$$

The constants C_1, C_2 are determined from the boundary conditions at the free edge $x = +l$, i.e. $\frac{d^2w}{dx^2} = \frac{d^3w}{dx^3} = 0$; and $C_3 = \alpha a$. Hence the constants C_1, C_2 are determined as,

$$C_1 = C_3 \frac{\left[\frac{T_l''}{\beta^2}(\sin\beta l/\cosh\beta l + \cos\beta l/\sinh\beta l) - \frac{T_l'''}{\beta^3}\sin\beta l/\sinh\beta l\right]}{\sin 2\beta l + \sinh 2\beta l} \qquad (3)$$

$$C_2 = C_3 \frac{\left[\frac{T_l''}{\beta^2}(\cos\beta l/\sinh\beta l - \sin\beta l/\cosh\beta l) - \frac{T_l'''}{\beta^3}\cos\beta l/\cosh\beta l\right]}{\sin 2\beta l + \sinh 2\beta l} \qquad (4)$$

The various stress-couples and stress resultants in the shell follow directly from Equation (2)[1] and the corresponding values of shell deflection and rotation at the free edges are:

$$w_{/T} = C_1 \sin\beta l/\sinh\beta l + C_2 \cos\beta l/\cosh\beta l - C_3 T_l \qquad (5)$$

$$\pm\frac{\theta_{/T}}{\beta} = \sin\beta l/\cosh\beta l(C_1 - C_2) + \cos\beta l/\sinh\beta l(C_1 + C_2) - \frac{C_3 T_l'}{\beta}. \qquad (6)$$

A simple example will now be considered. If T is assumed to have the form,

$$T = T_o + (T_l - T_o)\left(\frac{x}{l}\right)^3,$$

the longitudinal bending stresses at $x = 0$ can be expressed non-dimensionally as:

$$\bar{\sigma}_o = \frac{\sigma_o}{E\alpha(T_o - T_l)}$$

which is plotted as a function of βl in Fig. 1. If end effects in the shell are neglected, the variation of the same stress parameter is simply:

$$\bar{\sigma}_o = 1{\cdot}816\left(\frac{1}{\beta l}\right)^2 \qquad (7)$$

which is also plotted in Fig. 1.

For this example it may be concluded that the maximum longitudinal bending stress at $x = 0$ occurs when $\beta l = 1{\cdot}7$.

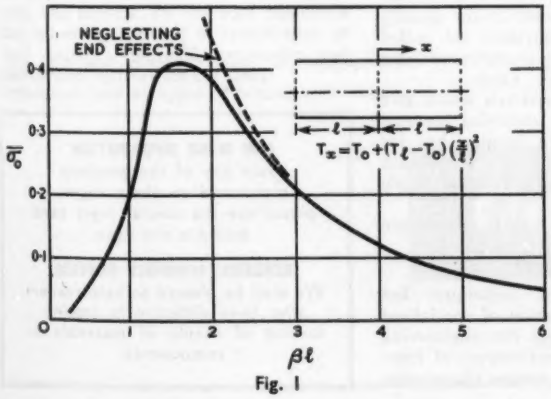


Fig. 1

Effect of Edge Restraint

Using the results of [1] it can be shown that edge deflections and rotations in the shell due to applied edge shears, Q_l, and moments, M_l, are given by:

$$w_l = \frac{-2\beta a^2}{Eh}\left[\beta M_l X_2 + Q_l X_1\right] \qquad (8)$$

$$\pm\theta_l = \frac{+2\beta^2 a^2}{Eh}\left[2\beta M_l X_3 + Q_l X_2\right] \qquad (9)$$

where $X_1 = \dfrac{\cosh 2\beta l + \cos 2\beta l}{\sinh 2\beta l + \sin 2\beta l}$

$X_2 = \dfrac{\sinh 2\beta l - \sin 2\beta l}{\sinh 2\beta l + \sin 2\beta l}$ $\qquad$ $X_3 = \dfrac{\cosh 2\beta l - \cos 2\beta l}{\sinh 2\beta l + \sin 2\beta l}$

and these functions are tabulated in Table 46 of [1].

If it is assumed that the edges of the shell are fully clamped the necessary conditions to be satisfied are that the resultant deflection and rotation should be zero. Therefore from Equations (5), (6), (8) and (9):

$$W_{/T} + W_l = 0 \qquad (10)$$

$$\theta_{/T} + \theta_l = 0, \qquad (11)$$

and solution of Equations (10) and (11) will give the values of M_l, Q_l.

If simply supported edges are considered, the edge rotation is not necessarily zero and solution of Equation (10) gives the value of Q_l with M_l equal to zero. The stress distributions in the short shell due to Q_l and M_l are easily determined from [1].

Such analyses have been made for shells of infinite length in [2] and [3], with allowance for thermal expansion and flexibility of the edge restraining member, e.g., bulkhead or frame. Such allowances could easily be incorporated in the present analysis.

References

1. Timoshenko, S. *Theory of Plates and Shells* McGraw Hill, 1940.
2. Przemieniecki, J. S. "Transient Temperature Distributions and Thermal Stress in Fuselage Shells with Bulkheads or Frames," *Jour. Roy. Aero. Soc.*, December 1956, 799-804.
3. Johns, D. J. "Thermal Stress in Thin Cylindrical Shells, Stiffened by Plane Bulkheads, for Arbitrary Temperature Distributions", *College of Aeronautics Note No. 83*, July 1958.

Notation

a	Radius of shell.
C_n	Constants in Equation (2), defined in text.
D	Flexural rigidity of shell $= \left[\frac{Eh^3}{12(1-\nu^2)}\right]$.
E	Young's modulus.
h	Shell thickness.
l	Shell semi-length.
m	Power of x in polynomial expression for T.
Mx	Bending moment per unit length.
Qx	Transverse shear force in shell per unit length.
T	Shell temperature rise, function of x.
w	Shell radial displacement (+ve inwards).
x	Co-ordinate measured along shell axis from mid-length.
$X_{1,2,3}$	Functions of βl defined in text [Equations (8) and (9)].
α	Coefficient of linear expansion.
β	Shell parameter $= \left[\frac{3(1-\nu^2)}{a^2h^2}\right]^{\frac{1}{4}}$.
ν	Poisson's ratio.
θ_l	Shell edge rotation $= \left(\frac{dw}{dx}\right)_l$.
σ_o	Longitudinal shell bending stress at $x = 0$.

Suffixes

o, l	at $x = 0$, l respectively.
T	due to temperature rise only, e.g., $w_l T$.

NOTE: T′ refers to differentiation with respect to x e.g., $T''' = \frac{d^3T}{dx^3}$.

Data by D. J. Johns, B.Sc., M.I.A.S.

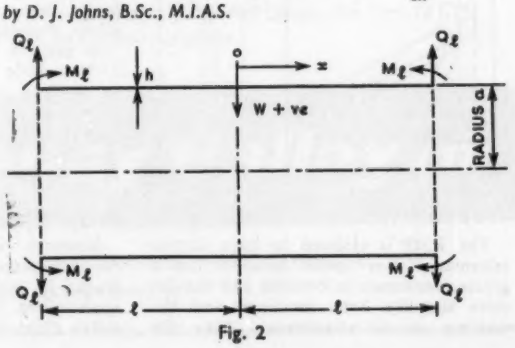


Fig. 2

WHAT'S NEW IN MATERIALS & COMPONENTS

Platinum Plating

Consistent-quality platinum plating, for high-temperature and other exacting industrial applications, is claimed for Platanex III/LS, a new low-stress platinum plating process originally developed in the U.S.A. but now available in the U.K.

It is claimed to produce a uniformly dense platinum electroplate in any practical thickness directly from the bath in one continuous operation.

The solution is supplied ready for use, and maintenance requires the addition of Platanex replenisher concentrate and/or water. The Sel-Rex formulation is said to make the bath exceptionally long-lived and to eliminate the noxious fumes encountered in ordinary platinum plating operations. M. L. Alkan Ltd.

EMD 566 for further information

Magnesium Alloys

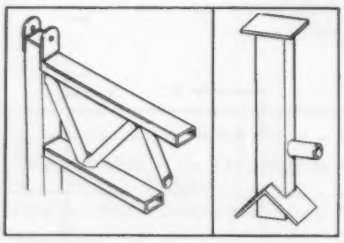
A new series of magnesium-base alloys containing silver, rare earth metals and zirconium has recently been developed and designated MSR alloys.

There are two variants, MSR (A) and MSR (B). They are claimed to have high proof stress, the values for which exceed those of any other magnesium alloy. It is claimed that proof stresses of 10-13¼ ton/sq. in. have been obtained, and that for the first time magnesium alloy castings directly comparable in this respect with high-strength aluminium alloy castings are available. The MSR alloys have a density 40 per cent lower than that of aluminium alloys. J. Stone & Co. (Charlton) Ltd.

EMD 567 for further information

Rectangular Hollow Sections

The rectangular hollow section (RHS) was originally developed as a cold-formed and annealed section, but is now superseded by a new range being produced by hot forming, with a consequent reduction in price. These sections conform to the physical properties of BS. 1775, Grade 15, and are supplied in 21-ft. lengths.

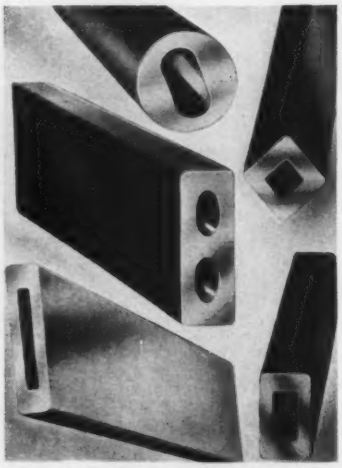


The RHS is claimed to have certain advantages over round tube. It has a greater resistance to bending and the flat sides simplify both junctions and the welding on of attachments. Like the round tube, it has great torsional strength and small surface area for painting. Stewarts & Lloyds Ltd.

EMD 568 for further information

Hollow Copper Conductors

A wide range of hollow copper conductors is now available for rotor and



stator windings of direct-cooled alternators and other electrical equipment.

These are made from H.C., Combarloy or other silver-bearing h.c. copper, and are supplied in straight lengths up to but not exceeding 20 ft. Thos. Bolton & Sons Ltd.

EMD 569 for further information

Chemical Brightener

A brightener for use in what is known as the "S" process is designed primarily for the treatment of super-purity aluminium, and its alloys with magnesium in the unpolished state where the economical and rapid removal of fairly large quantities of metal is required to produce a smooth, brightened surface. Aluminium of lower purity and alloys of the aluminium-magnesium and aluminium-magnesium-silicon types are said to react favourably, the extruded forms usually giving a better finish than the rolled forms. Some wrought aluminium-silicon alloys produce a bright finish.

In general, those materials which give a clear oxide film on anodising are said to produce acceptable finishes, but for maximum smoothness and brilliance high-purity material must be used. Acorn Anodising Co. Ltd.

EMD 570 for further information

Polyurethane Rubber

Research into new techniques has resulted in the production of specialised grades of polyurethane for engineering applications. The manufacturers of Prescollan claim that the unique characteristics of this material, particularly its high mechanical strength and extreme resistance to abrasion, make it of particular interest to engineers and designers who can exploit the facility with which it can be machined into components from bar stock. Suggested examples of components possible are O-ring seals, bearing bushes, bellows, small driving belts, gear wheels, diaphragms and valve seats, etc. Precision Rubbers Ltd.

EMD 571 for further information

One-can Etch Primer

What is claimed to be an improved etch primer has recently been introduced to combat rust and corrosion in metals. It is a new version of the Strathclyde etching primer (said to be the first one-can ready-for-use type in the U.K.); it is claimed to now have absolute stability and indefinite can life and to overcome entirely the "temperamental" features of its predecessors. The new primer, PA-10, ensures uninterrupted application by spray gun, and is equally effective applied by brush or by dipping—drying by any of these methods in thirty minutes. It may be stoved for quicker drying. Federated Paints Ltd.

EMD 572 for further information

Anti-static Spray

A general-purpose anti-static spray known as Croxtine has been announced. This product, in a self-spraying aerosol container, is claimed to prevent the problem of dust attraction on plastics, synthetic fibres and all other static prone materials.

Treated articles are said to remain cleaner due to a conducting layer left on the surface which dissipates any charges present and prevents any further charges being developed. The spray is said to be pleasant in use and the resulting film to be non-toxic, invisible, quick-drying and non-greasy. It is effective on all plastics and is particularly recommended in the treatment of plastics components in televisions, radios and refrigerators. The spray is said to be of advantage used on TV screens and also on instruments in preventing needle and dust attraction. Sheridan Croxted Ltd.

EMD 573 for further information

FOR MORE INFORMATION
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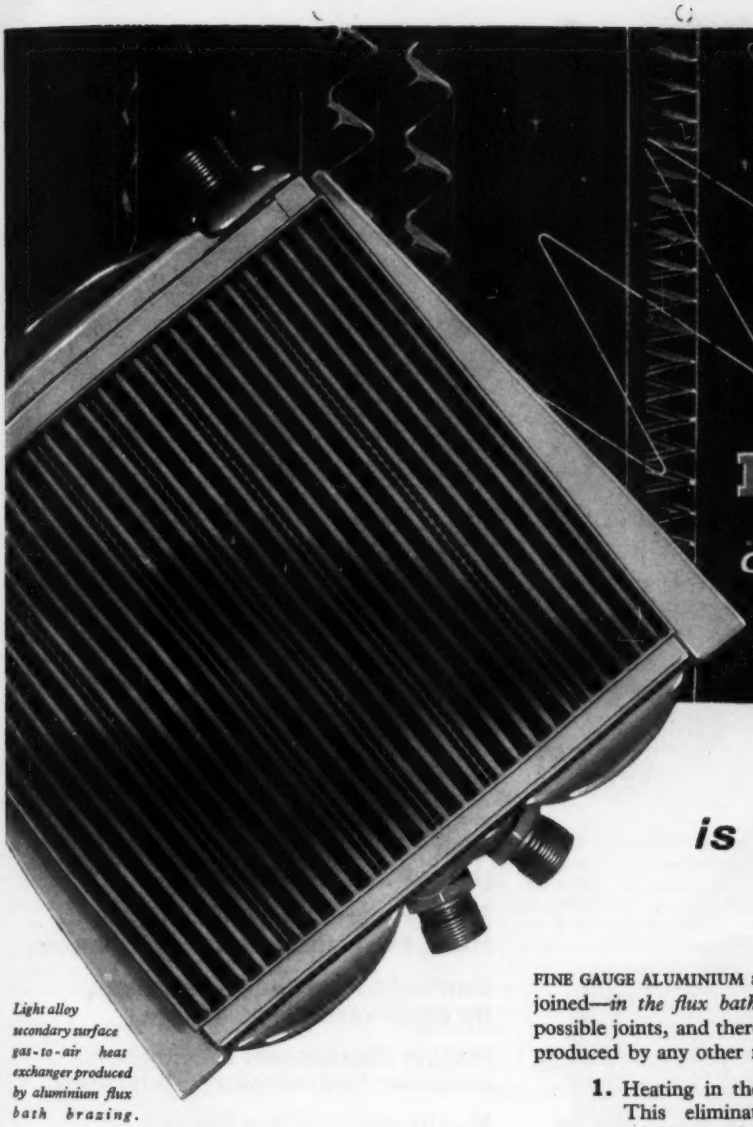

Light alloy secondary surface gas-to-air heat exchanger produced by aluminium flux bath brazing.

FLUX BATH BRAZING... of aluminium alloys

is the answer

FINE GAUGE ALUMINIUM and its alloys *can* be satisfactorily joined—*in the flux bath.* In fact, the flux bath makes possible joints, and therefore components, that cannot be produced by any other method. Consider these points:

1. Heating in the liquid flux is uniform. This eliminates all but the barest minimum of distortion and makes it possible to join metal as fine as 0·006 in.
2. Any number of inaccessible joints can be designed with complete confidence.

These two simple statements reveal a whole new field of opportunity for designing in aluminium and aluminium alloys—but, naturally, a certain 'know-how' is required.

We have this 'know-how', together with the bath. If you are interested in using them, please consult us. We shall be equally happy either to design for you or co-operate with your own designers.

We are specialists in heat exchange, heat insulation, and all types of brazing and welding.

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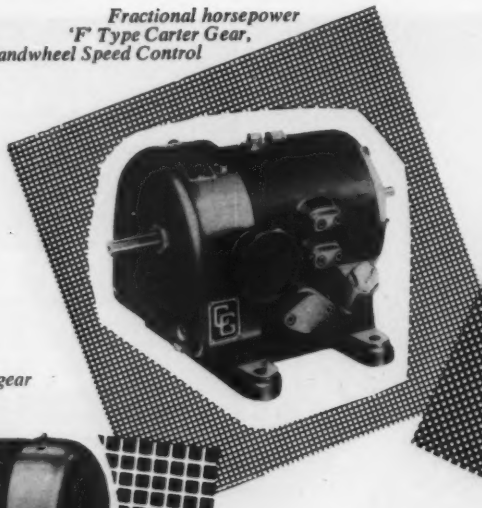
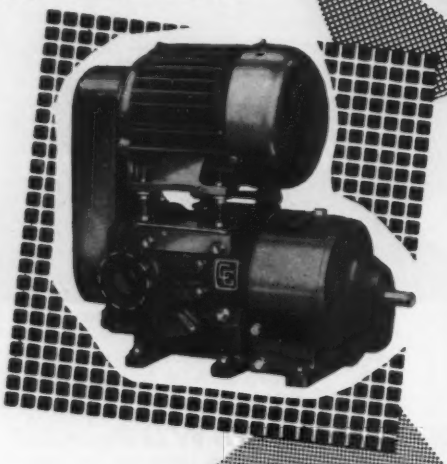
Fractional horsepower 'F' Type Carter Gear, Handwheel Speed Control



'A' Type Carter Gear, push button operated Remote Electrical Control

'F' Type Carter Gear, top mounted motor and flange mounted reduction gear



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Sensitive accurate speed control by Hand, Electrical or Lever arrangements.

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May be used as a clutch to pick up loads from zero r.p.m.

Controls may be operated with the drive either running or stationary.

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Continuous Galvanising

Speltafast is a special hot-dip galvanised sheet, coated on a continuous production line by passing cold-reduced strip continuously through furnaces with controlled atmospheres. This anneals the strip, and at the same time prepares the surface for galvanising without resort to the use of any flux.

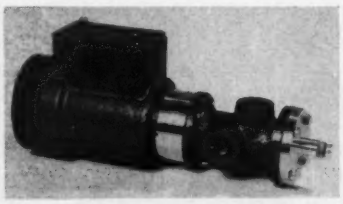
The brittle zinc iron alloy layers to be found in conventional hot-dipped galvanised sheet are said to be almost completely eliminated in the process—by the addition of a small amount of aluminium to the flux-free molten zinc. The result is a galvanised sheet with a zinc (spelter) coating that adheres to the steel base, even during severe forming and pressing operations.

The continuous galvanising operation is said to provide a far more uniform zinc coating than is normally possible in the case of ordinary hot-dip galvanised sheet. For similar coating weights, therefore, sheets and coil produced by this process should possess longer life. Speltafast is available in coil form as well as in plain or corrugated sheet. Richard Thomas & Baldwins Ltd.

EMD 574 for further information

Solenoid Valve

A new solenoid valve for overspill-type burners has been introduced which is suitable for use with fuel oil at viscosities ranging from 200-1,000 sec. Redwood No. I at pressures between 0.300 p.s.i. A special feature is the change-over switch operated by the valve spool which enables the operation of the valve to be interlocked with burner programme cir-

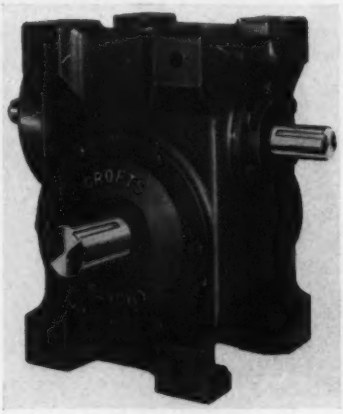


cuit to ensure that the correct sequence is initiated and/or maintained. It can also be used to operate a remote valve position indicator. The valve proper is of the balanced, slide pattern, the valve spool being controlled by a double-wound solenoid which is employed in order to provide sufficient power to overcome the initial stiction of the oil when the plant is started up from cold. To ensure maximum efficiency and quiet operation the solenoid is wound for 220 volts d.c., but a small chassis-mounted rectifier is available as an optional extra for use with a.c. supplies. Teddington Industrial Equipment Ltd.

EMD 575 for further information

New-style Gear Units

Two new types of gear unit, one being a worm reduction gear unit, the other a helical gear unit, are now available and have one common feature. By standardising the design of the outer casework and putting fixing holes in four faces, a great variety of mounting positions is possible. In the Universal worm reduction gear unit illustrated the simplified design is common to worm gears of the following types: standard (worm under wormwheel), inverted (wormwheel under worm), and vertical (wormshaft horizontal, wheelshaft vertical). The unit can be supplied in motorised form.



An advantage of the design is the quick and easy modification from one assembly to another, by either the customer or stockist, by the simple interchange of oil fillers, drain and level plug positions. The double extension wormshaft makes either right- or left-hand assembly possible by simply removing the fan and cowl and replacing them on the opposite end. The dimensions of the new unit are interchangeable with the essential dimensions of BS. 3027:1958. Crofts (Engineers) Ltd.

EMD 576 for further information

Assembly Device

Star tolerance rings are fastening devices which are interposed between machine parts required to be an interference fit. They are corrugated rings made from high-quality spring-steel strip

hardened and tempered. The manufacturers claim that with their use assembly of components which formerly would have necessitated close tolerance machining is now possible with much wider limits. They can be used to transmit a considerable amount of torque and eliminate the use of keys, splines, etc. They compensate for differential linear coefficients of expansion between machine parts, and maintain their grip over a wide temperature range. They also compensate for variations in machining tolerances, and automatically adjust for a degree of misalignment. Suitable for the fitment of handwheels, lever knobs, etc., they can also be used for mounting ball and roller bearings if certain precautions are taken. As the rings can tolerate a certain amount of differential expansion in the components to which they are fitted, they are particularly suitable for applications where bearings must be fitted to light alloy housings. They can also be used for reclaiming worn bearing housings. Geo. Angus & Co. Ltd.

EMD 577 for further information

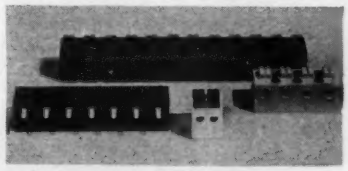
Rivet Bush

A new type of threaded rivet bush, which can be fitted with a single hammer blow, has a serrated face to prevent rotation. When secured, the serrated face forms an indentation in the sheet. Sizes from 5 B.A. to $\frac{1}{4}$ in. Whitworth and B.S.F. are available. Benton Engineering Co. Ltd.

EMD 578 for further information

Terminal Block

Damage to the strands of conductors is said to be eliminated in a new range of terminal blocks. The button over the inlet cable is depressed, the stripped cable end is inserted, the button is released and the cable is securely held in



position by two serrated contact pads. The blocks are claimed to be vibration proof and may be used with solid or stranded conductors up to $\frac{3}{32}$ in. in diameter. Four types are illustrated. Hellermann Ltd.

EMD 579 for further information

Lathe Indicator

The production of accurate length and depth in a longitudinal direction is a major difficulty in lathe work. The Ceewrite lathe indicator has been designed to make it possible to obtain any number of lengths and depths over the whole length of the lead screw to within limits of 0·001 in. It eliminates the use of depth micrometers, slip gauges, standard or vernier micrometers, and no time is lost in stopping the machine for checking purposes. The method of attachment will vary according to the lathe, but a method common to many lathes will be to attach the indicator to the saddle so that it will work on the lead screw. The indicator is manufactured in eight models, with either fractional or decimal dials and various settings. Alfred Herbert Ltd.

EMD 580 for further information

Service is a Tradition . . . .

We have always regarded the provision of a complete service, from design to finishing, as a major necessity between the conception of a product and its delivery to a market. That service, in the supply of zinc and aluminium die castings, is now traditional with us. Add to it our years of experience and we can present a very good reason why we are the largest pressure die casting organisation in the country, serving the needs of over 700 customers in 30 industries.

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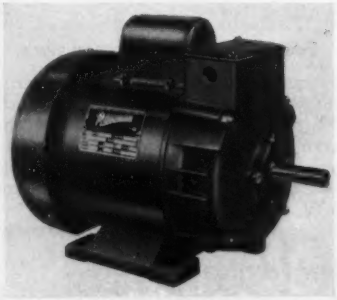
Totally-enclosed Motors

A new range of totally enclosed motors, ¼ to 2 h.p., in "66" frame dimensions (B.S. 2048 and NEMA Standard MG.1) is announced. The range has been designed to bridge the gap which usually exists between f.h.p. motors and the smallest of the industrial-type motors.



The main bodies of these motors are constructed from heavy-gauge sheet steel, the two end brackets being of cast iron. Fans and end covers are in diecast aluminium. On the single-phase version illustrated, a strong cover secured to the frame encloses the condenser, providing a protection against mechanical damage.

For compactness and ease of accessibility the terminal box is incorporated in the drive-end bracket with access through a cover plate on the top of the motor. Screwed conduit entries are provided on opposite sides with a blanking-off plug for the entry not in use. The single-phase motors incorporate a centrifugal switch in the non-drive end bracket and the rotating part is built from interlocking steel pressings with no hinge pins or other seizable parts. The static portion of the switch has heavy-duty, solid contacts and is enclosed in a dust-proof case. Thermal overload protection can be provided if required. Newman Industries Ltd.

EMD 581 for further information

Excess-flow Stop-valve

An excess-flow stop-valve is now in production for insertion in a liquid stream when it is desired that, in the event of the flow-rate exceeding a predetermined value of g.p.m., the liquid stream shall be stopped. After the liquid stream has been stopped by a valve closure, flow can be re-established only by manually re-setting the valve. The valve capable of being manually re-set against a liquid pressure of at least 160 p.s.i. Simmonds Aerocessories Ltd.

EMD 582 for further information

Diaphragm Meter

A mercury-less meter to measure a range of differential pressures from 20 in. to 200 in. of water at static pressures up to 2,000 p.s.i. uses an entirely new flexible diaphragm assembly. The new assembly has a number of advanced design features, i.e., a frictionless flexure-pivoted drive unit of exceptional sensitivity, positive protection against over-range with no zero shift, a simple method of range change, a built-in temperature compensation for all differential ranges and full-range damping which is adjustable under pressure. Foxboro-Yoxall Ltd.

EMD 583 for further information

Dual Pump

Measuring only 3 in. × 3¼ in. × 1¾ in., the PH. 171 is a positive-displacement pump which simultaneously pumps two liquids having widely differing chemical properties, each at a small but variable rate. The capacity of each delivery at 1,430 r.p.m. can be varied from one pint per hour down to almost nil. Pilgrims Way Motor Co. Ltd.

EMD 584 for further information

Braked Castor

In a new castor of 1-ton capacity an expanding brake is fitted which has an operating rod passing through the pivot spindle. Ferodo-lined shoes are housed in the wheel, which can be adjusted for clearance by an arcuate slotted quadrant.

Directional locking is provided by a vertical spring-loaded tommy-bar, the lower end of which engages in holes equally spaced in a horizontal circular plate, forming part of the castor-fork head. Tapered roller bearings are used in the swivel housing and wheel hub. The solid tyre has a dynamic capacity of 20 cwt., but if the castor assembly is fitted with an iron wheel the dynamic capacity is 30 cwt. The operating rod through the pivot spindle to lock the brakes may be pulled up or pushed down, whichever is more convenient for the type of chassis to which the castor is attached. Mild-steel rubber-tyred wheels are used for the braked castors and cast-iron rubber-tyred wheels for castors fitted with direction location only. Anti-static tyres can be provided if required. Autoset (Production) Ltd.

EMD 586 for further information

Air Silencer

A small silencer, known as the Muffl-Maze, has been developed to fit in the discharge port of pneumatic tools and appliances where a high-pitched exhaust noise can cause annoyance. Fitted with male thread connections from ¼ to ¾ B.S.P., the units can also be used as silencers on the free air inlet of small

compressors. The silencers can easily be removed for washing in any commercial oil solvent. Air-Maze Ltd.

EMD 587 for further information

Sprag Clutch

The sprag clutch can be used as a free wheel, a one-way or "hold-back" clutch, and as a means of indexing, and it is said that no backlash can develop throughout the working life of the clutch. In most cases the sprag clutch is supplied complete with sleeve or anti-friction bearings, thus eliminating the risk of misalignment and simplifying machine designs. Applications include dual- and multi-speed drives, stand-by drives, starters, conveyors and elevators, feed mechanisms, helicopters, transmissions, automatic gearboxes for cars, and four-wheel drives for commercial vehicles. Renold Chains Ltd.

EMD 588 for further information

Gas-tight Seal for Electric leads

Fine-drawn copper tubes, partly filled with solder, which are led through the neck of a brass ferrule and "potted" into position with synthetic resin, provide a method of sealing a small gas-tight container after wires have been passed through the case. Tests carried out with the seal fitted to an evacuated chamber containing an ionisation gauge have detected no leakage over a period of some months, and it was unaffected by temperature cycling from −40 deg. C. to +70 deg. C. The seal has also been found to be capable of withstanding considerable mechanical and thermal shock. The unit may be used at temperatures up to 100 deg. C. with a maximum pressure difference in excess of one atmosphere. Kelvin & Hughes Ltd.

EMD 589 for further information

AT THE PHYSICAL SOCIETY EXHIBITION

Among the exhibits seen at this year's Physical Society Exhibition in London, the following are of particular interest:

Impermeable Graphite

Normal graphite can be made impermeable to gases by impregnation with resins, but such materials cannot be used at temperatures over 200 deg. C. Recent work has led to the development of impermeable graphites not subject to such temperature limitations. A graphite tube was demonstrated in an evacuated chamber, the tube containing carbon dioxide under pressure and being heated by an electric current to approximately 600 deg. C. G.E.C. Ltd.

EMD 590 for further information

Permanent Magnet Alloy

A machinable sintered permanent magnet alloy, Comalloy, is now in production and should be of interest for many applications in industry. This alloy, which has a BH_{max} of about 1×10^6 gauss-oersteds, can be machined by normal methods prior to final ageing. Murex Ltd.

EMD 591 for further information

Magnetic Alloy

Supermumetal is claimed to be markedly superior to normal Mumetal. The typical normal induction curve for the material shows an initial permeability of 150,000 at a magnetising force of 10 micro-oersted and a maximum value approaching 500,000. Comparable values for ordinary Mumetal are 30,000 and 100,000 respectively.

In order to make full use of these enhanced characteristics, it is essential that designs be adapted to suit the new material, and not merely to replace the core material in the existing equipment.

Applications for which the material is said to give improved performance include precision current transformers, small inductors and chokes, microphone transformers and transductors. The Telegraph Construction & Maintenance Co. Ltd.

EMD 592 for further information

Capacitor for Ignition Units

A liquid-filled polyester film capacitor has been developed in collaboration with Rotax Ltd for aircraft ignition units. The outstanding feature of this component is that it will operate at 2,000 volts (pulse) over a temperature range of −50 deg. C. to +150 deg. C. G. V. Planer Ltd.

EMD 593 for further information

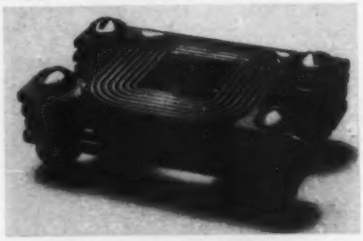
Silicon Transistors

A comprehensive range of silicon transistors is under development. These are all of diffused junction structure, and four basic types are in an advanced stage of development: (1) a high-frequency type with α cut-off 30 mcs.; (2) a general-purpose low-power type with α cut-off about 4 mcs. and collector dissipation 250 mW.; (3) a medium-power type with collector dissipation in the range 1 to 10 watts depending on heat sink; and (4) a high-power type, with collector dissipation up to 100 watts depending on heat sink.

Maximum collector voltages will be in the range of 50 to 100 volts, and maximum junction temperature 150 deg. C. These units are not yet generally available and further announcements will be made in due course. B.T-H. Co. Ltd.

EMD 594 for further information

Copper Circuitry on Glass



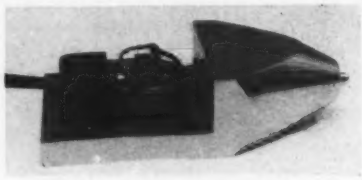
Copper-on-glass printed inductor.

A new type of printed circuit has been developed in association with Ferranti Ltd. under M.o.S. contract whereby copper up to 0·01 in. thick can be firmly bonded to a glass substrate. This opens up new possibilities for operation at very high temperatures, as the circuit is stable up to the softening point of glass or the onset of oxidation of the copper. The latter limit can be raised by overplating with a noble metal which can also be deposited directly on the glass. G. V. Planer Ltd.

EMD 595 for further information

Indium Antimonide Transducer

Magneto-sensitive resistor and Hall effect elements based on indium antimonide have been produced in association with Cosmoscord Ltd. Special types of Corbino disc elements have been used to manufacture variable reluctance transducers which have applications for displacement or proximity measurement, surface studies, pressure gauges, etc. Other elements are designed for flux servo devices and fluxmeters. The advantages claimed are high sensitivity, compactness and simplicity of operation. G. V. Planer Ltd.



Indium antimonide displacement gauge.

EMD 596 for further information

New Ferrites

The introduction of two new grades of Ferramic square loop ferrite has been announced. These are to be made available as alternatives to S4 and S5. Ferramic S4A has a similar switching time to S4, but has been modified to give higher output voltages at lower currents.

Because of a demand for a grade intermediate in performance between grades 4 and 5, Ferramic S5A has been developed with an optimum operating current of 460 mA., at which outputs are obtained significantly higher than those for S5 at its optimum current drive.

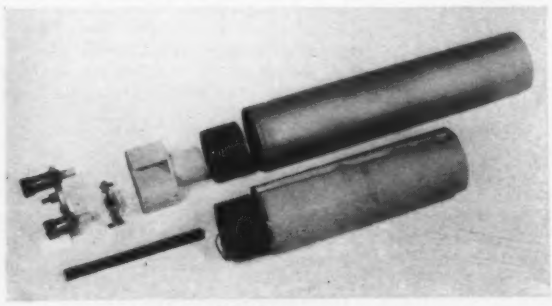
Ferramic S5 is now being produced in the 0·050-in. o.d. size, full drive amplitudes for optimum performance being about 250 mA. Plessey Co. Ltd.

EMD 597 for further information

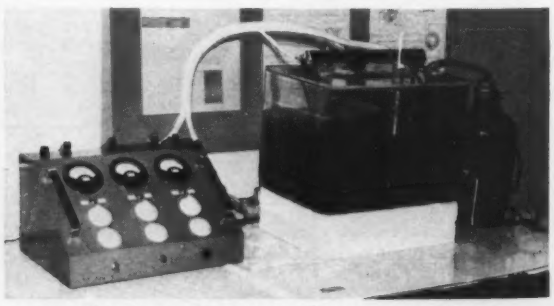
Oxides for Ferrites

An improved method of co-precipitating mixed oxide powders for the production of ferrites is said to give greater simplicity and economy with increased homogeneity and chemical purity. Developed in association with N.V. Magneto-Chemie, the method consists of electrolysing metal anodes corresponding to the oxides required in an alkaline electrolyte under oxidising conditions. Composition is adjusted by regulating each anode current. G. V. Planer Ltd.

EMD 598 for further information



Polyester film capacitor ignition unit.



Electrolytic co-precipitation of ferrite constituents.

EMD 527 for further information

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EMD 528 for further information

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News of Industry

A joint committee sponsored by the **Institute of Welding,** the **Plastics Institute** and the **British Plastics Federation** has been set up to consider the "technological needs of industry as regards the welding of thermoplastic materials".

The Vitreous Enamel Development Council has opened new premises at 28 Welbeck Street, London, W.1. Telephone number: Hunter 2237. The council has announced the appointment of Mr. Ken Jones as general manager.

The U.K.A.E.A. is inviting applications for the next course for senior technical executives in industry to be held at Harwell from June 15-25. Fee for the course is fifty guineas.

The Machine Tool Trades Association has revealed details of a scholarship for an advanced course in machine tool design at the Manchester College of Science and Technology. The course will be of two years duration and applicants, between the ages of 21 and 30, will be drawn from existing young designers and from engineering graduates with practical experience on the shop floor and in the drawing office.

Ten scholarships will be awarded each year to the value of £500 each. The course will commence next September.

A strong plea for uniformity and consistency in the technical terms currently used in missiles and aircraft was made by Sir Frederick Handley Page recently to an international gathering of missile technicians and Service personnel at the **College of Aeronautics.**

He said that although some confusion was caused by the diversity of European languages, the problem was serious enough in Britain alone, where certain technical expressions used in the aircraft industry were not accepted in guided missile work. He said he felt that it was time some standardisation was introduced.

Sir Frederick, who is chairman of the college governors, was speaking at the end of a two-day symposium at which former and present students took part.

The Sheffield sales office of **Brook Motors Ltd.** has now been moved to larger premises at Saxone House, 4 George Street. Telephone number is unchanged.

Office and works of **Amos of Exeter Ltd.** are moving to new premises at Weircliffe Court, Exwick, Exeter, with effect from March 2.

Mr. J. G. P. Anderson has been appointed manager of the development and research department of Crompton Parkinson Ltd.

Sales departments of **Furnival & Co. Ltd.** have been moved to Waterloo Engineering Works, Stockport, Cheshire. Two divisions have been formed in the company, one to deal with the sale of printing and paper cutting machinery, the other with the marketing of the Andantex reduction pulley.

Norton & Gregory Ltd. have announced that all distribution of their drawing office materials and equipment is now being handled by Lawes Rabjohns Ltd.

Microcell Ltd. announce that agreement has been reached in principle for the merger of that group of companies with the B.T.R. Industries Group.

Airmec Ltd. recently held in London an exhibition of its range of electronic instruments and industrial equipment. Among the less familiar equipment shown was a feeding hopper that will deliver small articles at rates up to 6,000/min. in single file. It will handle disc-shaped objects such as bottle caps, washers, tablets, biscuits, buttons, etc., from $\frac{1}{16}$ in. to $1\frac{1}{2}$ in. dia. and from $\frac{1}{16}$ in. to $\frac{5}{16}$ in. high. A photocell and lamp are incorporated and the electronic impulse may be applied to an electronic counter. The company is also marketing an electronic pea sorter which sorts good and bad peas by means of their colour.

Metal & Pipeline Endurance Ltd. have been appointed official consultants and cathodic protection designers to the Government of Trinidad and Tobago.

The Duke of Edinburgh recently paid a special visit to the **Production Engineering Research Association** for an inspection tour of the work carried out in the Melton Mowbray headquarters.

A new class of membership has been created by the **Engineering Centre,** Birmingham. For a fee of £10 10s. a year, British engineering firms can become associate exhibitors, which will enable them to use the centre's information service and other amenities.

Large-scale models were used to illustrate the operation of electronic sorting and computing equipment at this year's I.E.E. Faraday Lecture by Dr. H. A. Thomas on "Automation" at the Royal Festival Hall. Photo shows one of the models being controlled from the console.

Sir Gordon Russell will retire from the directorship of the Council of Industrial Design at the end of this year. Mr. Paul Reilly, at present deputy director, will succeed to the post of director at the beginning of 1960.

The Mond Nickel Fellowships Committee is inviting applications for the 1959 awards. The main object of these is to enable selected British applicants with university degree or equivalent standard to obtain additional training and wider experience in industrial establishments at home or abroad. Each fellowship will occupy one full working year, and will be to the value of £900 to £1,200 each.

Mr. L. E. Wingfield has resigned from E. G. Irwin & Partners Ltd. in order to establish a design consultancy practice, specialising in engineering and domestic products.

The **"Plastics-59"** trade fair, which is to be held in Düsseldorf from October 17-25 this year, promises to be one of the most comprehensive shows of its kind in the world. The organisers of the fair recently met to examine and select the exhibits which are being offered.

Designer's Diary

Mar. 3. I.E.E. "Small Squirrel-cage Motors". College of Further Education, Loughborough. 6.30 p.m.

Mar. 3. Cement & Concrete Assoc. "Prestressed Concrete Tanks". The Temple, 24 Dale Street, Liverpool. 6.30 p.m.

Mar. 10-11. Coll. of Prod. Technology. Two-day course on "Materials and Design for Engineers, Scientists and Designers". Caxton Hall, London.

Mar. 11. Inst. of Production Eng. "Production, Fabrication, Properties and Uses of Some of the Newer Metals". Dept of Mech. Eng., University of Birmingham. 6.30 p.m.

Mar. 16. I.E.E. "Insulation and Insulation Testing". S. Wales Inst., Park Place, Cardiff. 6 p.m.

Mar. 17-21. Electrical Engineers' Exhibition. Earls Court, London.

Mar. 18. Inst. of Plant Eng. "Some Applications of Plastics in Industry" King's Head Hotel, Rochester. 7 p.m.

Mar. 20. Inst. of Prod. Eng. "Engineering Ceramics". S. Wales Inst., Park Place, Cardiff. 7 p.m.

Mar. 26. Inst. of Plant Eng. "Refractories". Grand Hotel, Sheffield. 7.30 p.m.

Apr. 16-30. Engineering, Marine, Welding & Nuclear Energy Exhib. Olympia, London.

Apr. 29. Powder metallurgy joint group of Iron and Steel Inst. and the Inst. of Metals. Meeting postponed from March 12.

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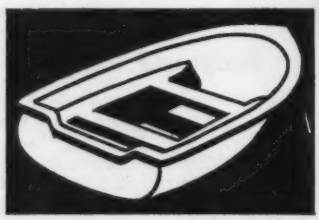

UCC
CHEMICALS FROM COAL

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